Chemical Engineering Progress

PUBLISHED MONTHLY BY THE AMERICAN INSTITUTE OF CHEMICAL ENGINEERS





TURBO-MIXER, a division of

GENERAL AMERICAN TRANSPORTATION CORPORATION

TURBO INSTALLATION at Duval Potash Refinery





Left: Turbo Slurry Mixers suspending ground potash ore

Below: Turbo-Floaters separating ground potash slurry in the roughing and cleaning circuits





The modern Duval Sulphur & Potash Company plant recently opened at Carlsbad, New Mexico uses Turbo-Mixers exclusively in the refining operations. The

Turbo-Mixers handle the major slurry suspension operations before and after flotation. The Turbo Floaters for the froth flotation of the potash ore are similar to the Turbo Floaters in the service of other refineries in the Carlsbad field. Here is another example where an industrial leader called upon Turbo-Mixer to supply creative mixing

devices for continuous duty - 24 hours a day - every day. Call on Turbo for specialized help in supplying controlled agitation for optimum results.



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Number 12

Chemical Engineering Progress

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Press-I-Cell PRECISE PRESSURE CELL

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SCALE -

600-in. tape, continuous and usable

The Press-I-Cell is a deflection type instrument for the precise indication of absolute, gauge and differential pressures. It also is applicable in precision liquid level and specific gravity determinations.

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In this system, low voltage contacts are mounted on the flexure arms and on the follow-up cradle. The follow-up cradle is operated manually by a hand crank to a point of measurement balance, indicated by a change from red to green at bull's-eye light at the scale. Pressure is read by comparing the scale against a hairline. Conventional flashlight batteries are mounted inside the case and are conveniently accessible.

9 Servo-Operated System

Here, small armatures are mounted on the flexure arms, and coils to complete the inductance bridge are mounted on the fol-



Compact 5" (dium.) panel mounting digl.

low-up cradle. The unbalance current is amplified to drive a balancing motor which restores the cradle to a null or balance position, simultaneously positioning the tape scale. The high gain amplifier is mounted in a 3"x 8"x 8" case.

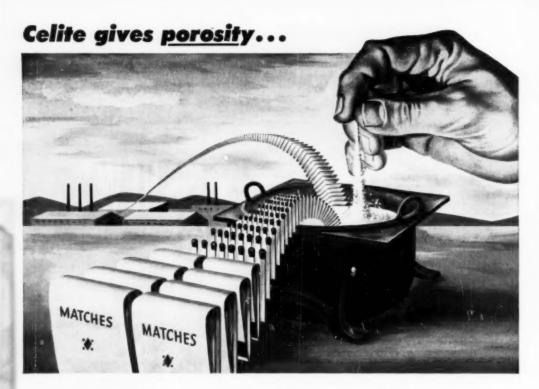


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Adding "Safety Valves" to match heads

Incorporated in match heads, Celite Mineral Fillers act as "safety valves" to prevent flare-up and kill afterglow.

The explanation: Celite's porous, thinwalled, cellular structure gives the match heads greater porosity so that gas can escape quickly.

Celite's abrasive quality also makes matches easier to strike. And from a production line standpoint, the high absorptive capacity of this mineral filler speeds drying of the match heads . . . while its light weight and great bulk improve dispersion of the active chemicals in the match head mix.

These and other unusual physical characteristics adapt Celite Mineral Fillers to numerous industrial uses.

THESE CELITE PROPERTIES BENEFIT MANY TYPES OF PRODUCTS

Celite's minute, chemically inert particles have an irregular, spiny structure—which accounts for their efficiency as a delicate abrasive in polishes, as a flatting agent in paints, varnishes and lacquers, and as a reinforcing agent for paint films and rubber products.

Celite powders can absorb up to three times their own weight of liquid—making them particularly useful in preventing ammonium nitrate crystals from caking, in absorbing liquid insecticide poisons, and in controlling pitch trouble at paper mills. And because the loose

weight of Celite averages only 10 pounds per

weight of Celite averages only 10 pounds per cubic foot—these mineral fillers are employed to fluff-up insecticide dusts and household cleansers, as well as to extend white pigments in paper manufacture.

If you are looking for the "extra something" to lift your product above competition—at no extra cost—why not discuss your problem with a Johns-Manville Celite Engineer? For further information and samples, write Johns-Manville, Box 60, New York 16, N. Y. In Canada: 199 Bay Street, Toronto 1, Ontario.

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- Added Bulk
- Better Suspension
- Faster Cleaning Action
- Greater Absorption
- Improved Color
- Better Dielectric
 Properties
- More Durable Finish
- Increased Viscosity
- Elimination of Caking
- Higher Melting Point
- Better Dry Mixing
- Improved Dispersion
- Greater Parasity



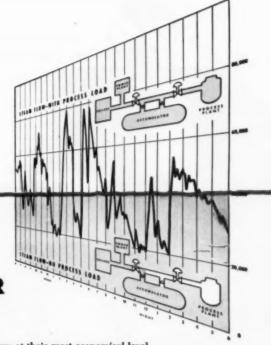
Johns-Manville CELITE

MINERAL FILLERS

balancing steam supply and demand

economically automatically with the

FOSTER WHEELER ACCUMULATOR



Now you can operate your boilers at their most economical level, and automatically supply constant-rate, high-pressure steam to your power plant plus steam for the severe fluctuating needs of your process departments.

The Foster Wheeler Steam Accumulator automatically takes the "awings" of intermittent high-steam demand by storing the heat energy of steam in a large quantity of water under pressure, and at saturation temperature, and releasing the energy in the form of steam at a lower pressure. Thus, with the boiler plant operating at its most economical constant rate, the accumulator will receive, condense and store steam during periods of low process-plant demand and return it to the steam lines during periods of high demand in the processing departments.

REDUCES REQUIRED BOILER CAPACITY

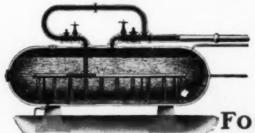
In plants without an accumulator, boiler capacity to meet peak process loads may need to be double the average load. However, where an accumulator is installed, boiler capacity need only be sufficient to meet the average load. Thus a reduction is made possible in the size or number of boilers required.

INCREASES BOILER EFFICIENCY

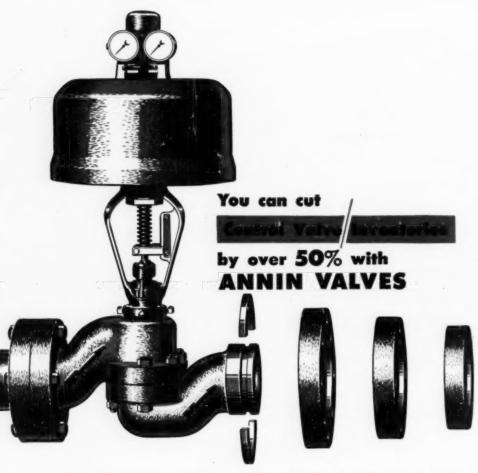
The constant load at which the boilers operate in conjunction with an accumulator, plus the ability of the accumulator to supply all peak demands, assures constant steam pressure, maximum efficiency and capacity in both power generation and process work.

Each Foster Wheeler Accumulator is designed to meet the particular requirements in your plant. Installations have been made as small as 200 cu., ft. and as large as 176,000 cu. ft. Send us the details of your problem today. Write to:

FOSTER WHEELER CORPORATION 165 BROADWAY, NEW YORK 6, N. Y.



FOSTER WHEELER



Designed for maximum interchangeability of valve bodies, flanges and operators



The Annin Domotor valves provide positive control of corrosive, erosive fluids and fluids containing semi-aclids.

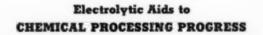


Because all Annin valve bodies carry 1000 # ratings, interchangeable flanges in Series 15, 30 and 60 can be mounted with split-rings on any Annin valve body to meet the requirements of practically any installation. One body, mounted with proper flanges, can be used anywhere in the plant. In addition, any Annin operator—Domotor, Electro-Pneumatic, Handwheel—fits two sizes of any valve body. Thus it is unnecessary to stock spares for every valve type and size you use. Most Annin users report great reductions in necessary valve stocks from 50% to 75% and more!

This reduction in inventory, plus considerable reductions in maintenance costs make the Annin Valve one of the most economical to operate in your plant. It will pay you to investigate today the many advantages of Annin Control Valves. Send for Catalog 1500B.

Annin Catalog 1500B describes all Annin Valves, tells how Annins reduce inventories and cut maintenance costs. Send for your copy today!

THE MININ COMPANY OF THE PROPERTY OF THE PROPE



The newly designed, high capacity Hooker Type S-3 cells are playing an increasingly important part in the production of "workhorse" chemicals for the process industries.

Uniformly high quality GLC Graphite Anodes are doing their share to help the electrolytic industry meet the ever increasing civilian and defense demands for chlorine and caustic soda.

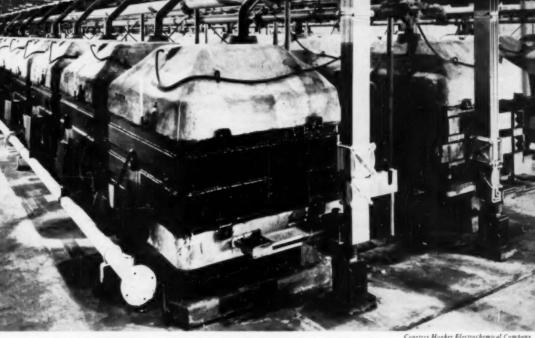
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Great Lakes Carbon Corporation

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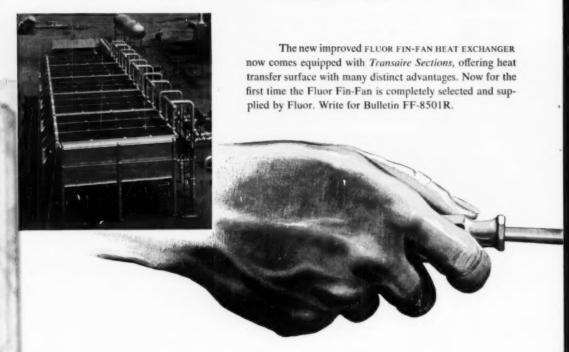


Graphite Anodes, Electrodes and Specialties -

Sales office: Niagara Falls, N. Y. Other offices: New York, N. Y., Chicago, Ill., Pittsburgh, Pa.

Sales Agents: J. B. Hayes, Birmingham, Ala., George O'Hara, Long Beach, Cal., Great Northern Carbon & Chemical Co. Ltd., Montreal, Canada.

Announcing the <u>NEW</u> improved.

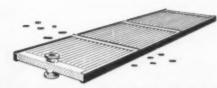


The design features of Transaire Sections appreciably hold velocity pressure loss to a minimum, provide smoother flow into and from tubes with a reduction in turbulence, increase cooling capacity at lower horsepower, increase the safety factor, and offer desirable features unobtainable in other aircooled heat exchangers of conventional design.

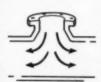
The Fluor "truss-type" steel structure remains essentially the same. The plenum design, the trouble-free performance of Fluor mechanical equipment, the uniform prefabrication of parts, the adaptability to almost any new duty involving pressures to 5,000 p.s.i. and temperatures to 1,500°F—these have been retained.

BE SURE WITH HILLOR CORPORATION, LTD. LOS ANGELES 22, EALIFONNIA FORTICAL FACTOR OF AN ALL FLUOR OF CANAGA TORON TO FLUOR INTERNATIONAL SELECT MEAD WHIGHTSON LONDON MANUFACTURERS MANUFACTURERS MINIMINAM TULSA





Transaire Sections offer these advantages:



1. Less pressure drop

Inlet and outlet nozzles in the headermanifold allow for a full pipe cross sectional area opening into the header with curved entrance to keep velocity pressure loss at a minimum. Note how the nozzle widens out below the inlet flange permitting a smoother, more natural flow into the header. Tube holes are taper countersunk for the same reason.



2. Four-to-one safety factor

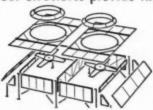
Headers are either cast iron or fabricated steel and in either case are unconditionally guaranteed to withstand test pressures of four times the design pressure. Brass header plugs provide quick easy access to tube ends for cleaning or replacement without requiring special tools.



3. More heat transfer surface

Fins are crimped, and crimped fins present more surface area to tubes which in turn means more metal-to-metal contact and greater dissipation of heat. The crimp also presents more fin surface to passing air. Tubes are available either in admiralty, steel or other materials as required. Fins of copper or atuminum.

Fluor Structures provide these advantages:





Fluor Fin-Fans are adaptable to available space. They may be connected in series for long temperature ranges, or in parallel for large capacities. Single units can be used for multiple duties in widely diversified applications economically a d at low maintenance costs. Parts are simple and

standardized to save erection time in the

3. Meet space requirements

1. Rigidity of steel





Mechanical equipment for Fluor Fin-Fans is built to withstand the most rigorous heat transfer requirements. 4 basic gear units cover 4 different and distinct horsepower ranges. This, coupled with a choice of fan assemblies ranging up to 20' diameter with 2, 3, 4 or 6 blades per fan unit, enables the proper combination of gears and fans for maximum efficiency.



Do You Know the "Ins and Outs" of these

Pfizer

· Unwanted traces of iron, aluminum, copper and other metals picked up from pipe lines and processing equipment can be rendered inactive by the use of a Pfizer sequestering agent. You can put "in" Pfizer Citric or Gluconic Acid-or one of their derivatives* - to sequester "out" the metallic contaminants which interfere with efficient operation in your plant.

Pfizer Citrates and Gluconates are recommended as sequestering agents in...

The textile industry...to inactivate trace metals in dyeing, bleaching, kier bailing and mercerizing.

The leather industry...to adjust tanning solutions to the proper pH without precipitation.

Oil and fat industry...to inactivate trace metals which lead to rancidity

Weed killer fermulations...to prevent fermation of insoluble, inactive salts in hard water greas,

Municipal and industrial water systems...to prevent the precipitation of metallic contaminants.

*Sodium Citrate, Sodium Gluconate,

PUT "IN"	SEQUESTER	"OUT"	pH
CITRIC	Iron (Ferric)	19 Parts	7
CITAL	Aluminum	19 Parts	7
ACID	Copper	26 Parts	7
	Zinc	44 Parts	7
Sequestering action of 100 parts of acid	Cobalt	95 Parts	10
CHICONIC	Iran (Ferric)	24 Parts	7
GLUCONIC	Aluminum	4 Parts	7
ACID	Copper	26 Parts	7
	Zinc	27 Parts	7
Sequestering action of 190 parts of acid	Cebalt	6 Parts	10

Pfizer has a wealth of information on the effectiveness of these Citrate and Gluconate sequestering agents. For additional data, write:

CHAS. PFIZER & CO., INC.

630 Flushing Ave., Brooklyn 6, N. Y.
Offices: Chicago, Ill.; San Francisco, Calif.; Vernan, Calif.

Ammonium Gluconate



Manufacturing Chemists for Over 100 Years

IMPORTANT ANNOUNCEMENT! FACTORY CAPACITY HAS BEEN DOUBLED! DELIVERIES ARE GETTING MUCH BETTER!

HAVEG is not a tank lining or coating. It is a solid, molded non-metallic material that the HAVEG CORPORATION fabricates to your specifications in its Marshallton, Delaware plant. Large size equipment can be molded in single pieces without seams or joints at low cost. Tanks can be made in one seamless piece as large as 10 feet in diameter by 12 feet in depth. HAVEG resists the corrosion effects of practically all acids, bases, and salts.

ANKS

Plain Rat Haves cover

HILLIED

Flat loose Haves cover will

angle-iron reinfercing ribs

and in the

Dished loose Haveg col Prince

SLOPING BOTTOM TANKS

Sidewall outlet

Center outles

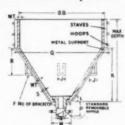
From TOPS Where tanks are vented to the atmosphere, four types of covers may be obtained. HAVEG can be machined and repaired readily so that pipe connections, manholes, changes to the system present no problem to the installation and maintenance crew.

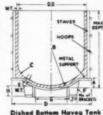
HAVEG CYLINDRICAL TANKS CUT COSTS . . . RESIST CORROSION

Here are tanks with amazing long life, through and through resistance to corrosion! HAVEG cylindrical tanks have been successfully used for storage, pressure, pickling, and separating tanks, dye vats, crystallizers, surge tanks and stills. Consult your nearest HAVEG engineer now for technical advice, delivery, and price information. Specify HAVEG corrosion resistant equipment . . . tanks, towers, pipes, valves.

To BOTTOMS

Get the best bottom for the process with molded HAVEG. Sloping bottom tanks can be provided with outlets at any location. For more complete drainage, dished bottom tanks are available and when suspended solids are present, cone bottom tanks can be provided.





Cone Bottom Tank for applications requiring complete drainage.

Write Today for a complete 64page, illustrated, technical bulletin on HAVEG corrosion resistant equipment. This Bulletin F-6 has chemical resistance tables for various HAVEG grades, tank sizes, installation and machining information. If you have a corrosion problem, HAVEG can help you. Write Now!



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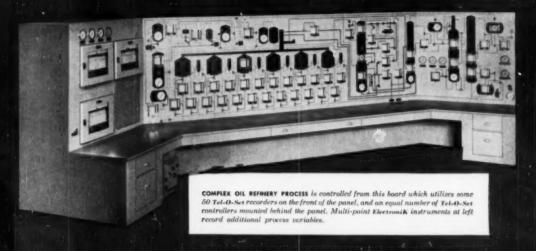
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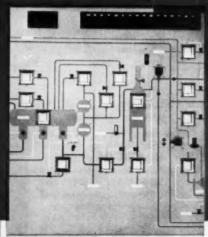
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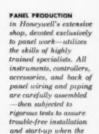
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Pan-Am Southern



FUNCTION-DESIGNED CONTROL for a large refinery includes this section in a large graphic panel by Honeywell—using front-of-panel Liquid Level Indicators and Tel-O-Set recorders, plus Tel-O-Set controllers behind the panel.



panel reaches your plant.



Shown at the left are just two of the many graphic instrument panels which Honeywell has supplied for centralized control of a wide variety of industrial processes. Each one is the result of well-seasoned engineering know-how... based on extensive Honeywell experience... which combines all instruments and accessories into a closely integrated, efficient design.

Whether your process calls for a full graphic or semi-graphic panel . . . a conventional board . . . or a control cubicle . . . you can be sure of obtaining every feature of quality and performance that you need in a Honeywell panel.

In Honeywell's Panel Division, meticulous attention to engineering detail and highly developed construction techniques watch over every step—from blueprint to assembly to final test. Add to this engineering and manufacturing skill the availability of a complete line of conventional and miniature instruments, and the result is a control board . . . custom-fitted to your needs . . . that makes Panels by Honeywell synonymous with the best in centralized control.

Our local engineering representative will be glad to discuss how graphic panels by Honeywell can bring new efficiency to your processes. Call him today . . . he is as near as your phone.

MINNEAPOLIS-HONEYWELL REGULATOR Co., Industrial Division, 4427 Wayne Avenue, Philadelphia 44, Penna.

Honeywell

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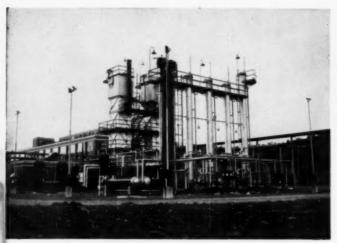


First in Controls

Write for your copy of Bulletin No. 85-20, "Centralized Instrumentation . . . unlimited."



Girdler Process News



Girdler HYGIRTOL* Plant at U. S. Bureau of Mines Synthetic Liquid Fuels Plant . . . supplies both pure hydrogen and various mixtures of synthesis gas.

Complete engineering-construction service assures a job "well done"

Por Process Plants in the Chemical, natural gas, and petroleum industries, Girdler assumes unit responsibility for design, process engineering, and construction. This saves you engineering manhours and time. Most important, it assures proper coordination of the whole project and successful results.

Girdler has broad experience in handling complete "process packages" ... covering design and construction of process plants involving very high operating pressures, high temperature reactions, and corrosive substances.

For the first step in your planning, obtaining factual data for evaluation, Girdler offers cost-plus contracts covering preliminary engineering . . . process recommendations, flow diagrams, general equipment specifications, plot plans, cost estimates, and operating cost data. This simplifies planning, and assures sound decisions. For a job "well done", call on Girdler in the planning stages of your processing facilities.

*HYGIRTOL is a trade mark of The Girdler Corp.



PROCESS RESEARCH—Girdler's research and development department is well equipped to assist with all types of process problems. A technical staff is available for consultation, and Girdler's research group can be employed on special problems at reasonable cost.



ENGINEERING—Experienced executives direct a group of engineering specialists, trained for every job requirement. In addition to basic process and equipment design, Girdler engineers have broad experience in buildings, foundations, electrical systems, boiler plants, instrumentation, etc.



ON-THE-JOB—Girdler engineers supervise and direct all phases of construction. When the job is completed, experienced operating engineers will start up the plant, train operating personnel, run acceptance tests, and supply complete operating data.

Want More Information?

Girdler's Gas Processes Division designs and builds plants for the production, purification, or utilization of chemical process gases; purification of liquid or gaseous hydrocarbons, manufacture of organic

compounds. Write for Booklet G-35 The Girdler Corporation, Gas Processes Division, Louisville 1, Kentucky. District Offices New York, Tulsa, San Francisco. In Canada: Girdler Corporation of Canada Limited, Toronto.



The GIRDLER Corporation

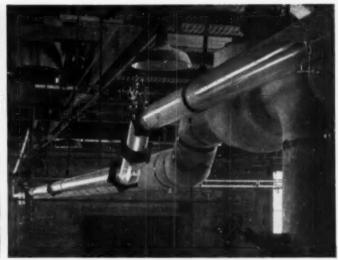
LOUISVILLE 1, KENTUCKY
Gas Processes Division

GAS PROCESSES DIVISION: Designers, Engineers, and Constructors for the Petroleum and Chemical Industries

VOTATOR DIVISION: Processing Apparatus for the Food and Chemical Industries
THERMEX DIVISION: Industrial High Frequency Dielectric Heating Apparatus







What to consider

IN SELECTING CHEMICAL PLANT PIPING

IN specifying process pipe it is important to give proper weighting to replacement costs, maintenance, ease of cleaning and the visibility of a process. That's why it may pay you to review these facts about PYREX brand "Double-Tough" glass pipe:

Corrosion Resistance—Glass pipe provides corrosion resistance to an extremely wide range of chemicals. It withstands the effects of all acids, except hydrofluoric, and can be used with all but exceptionally strong caustics.

Visibility — Only glass permits you to actually see what is happening—helps you to keep a continuous check on your process.

Ease of Cleaning—The glass-smooth surface of PYREX pipe assures simple rapid cleaning by flushing. There are no truncations or grooves in which deposits can collect to foul the pipe or to contaminate sensitive solutions.

Rapid Assembly—PYREX pipe and fittings are designed for rapid installation even by inexperienced help. Field plumbing kits permit you to make odd lengths right on the job as shown at right above.



Cutting odd length is simple

Low First Cost—The initial cost of PYREX pipe is definitely in line with that of other chemical piping materials actually lower than most.

Low Replacement Costs — Not only corrosion resistance, but high resistance to both physical and thermal shock contribute to long service life. People respect glass, treat it carefully. Records prove that PYREX pipe is a genuine bargain.

AMONG the biggest and most enthusiastic users of PYREX pipe today are those who tried a small installation "just to see how it would work." Why not you? There is a PYREX pipe distributor near you. He carries the complete line, including all fittings. Corning will gladly send you his name on request. Use the coupon below.

CORNING GLASS WORKS Dept. EP-12, Corning, N. Y.

Please send me the printed information checked below:

- "PYREX brand "Double-Tough" Glass Pipe and Fittings" (EA-3)
 - "PYREX brand Glass Pipe in the Process Industries" (EA-1)

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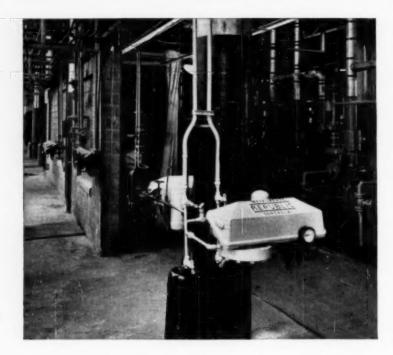
_

.

Street.

City

Zone___State.



These Meters Had To Be ACCURATE — FLEXIBLE — RUGGED

One hundred twenty one Republic Pneumatic Transmitters are measuring the flow and level of various acids in a large chemical processing plant, a section of which is pictured above.

These transmitters have a guaranteed accuracy of within $\frac{1}{2}$ of 1% of the transmitter range. By making a few minor adjustments or substituting a few small parts, their operation can be easily changed to any desired range between a minimum of 0-0.6" of water to a maximum of 0-704" of water. Their construction is more like that of a precision machine than of the sensitive instrument they are. It is for these reasons that Republic Pneumatic Transmitters, even though comparatively new, have already

been specified and installed on over 2500 industrial metering applications.

Republic Pnuematic Transmitters are available for measuring flow, liquid level, pressure or liquid density of a wide range of fluids. They employ the force-balance principle to convert these process variables into air pressures which vary proportionally. These air pressures become direct measurements and can be conducted to reading instruments or used as the measuring impulse for the actuation of an automatic controller.

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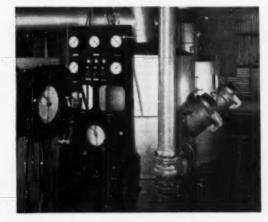
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Where processes call for vacuum pressures down to 50 microns (.002" Hg abs), the I-R Steam Jet Ejector can generally make important savings in first cost, installation, operation and maintenance.

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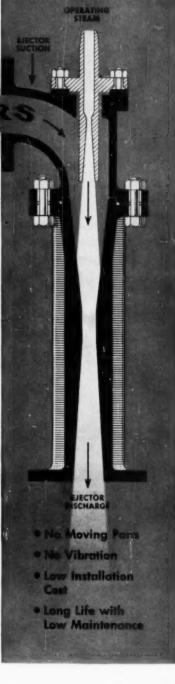
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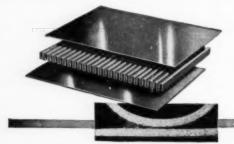
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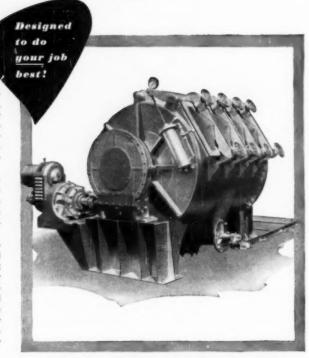
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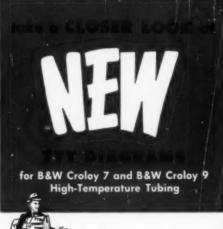
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Finding new facts about the behavior of alloy, stainless, and carbon steel tubing to help users with application and installation problems is a regular major function of the B&W Technical Service. For example:

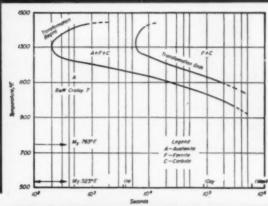
Isothermal transformation data recently were made available for the first time on B&W Croloy 7 and B&W Croloy 9 tubing. Extensive research and tests on these two popular intermediate alloys for high-temperature services provided sufficient data to construct the time - temperature - transfor-mation diagrams reprodued on the opposite page. They furnish helpful information relating to the heat treatment, general fabricating and welding, and particularly the hard-

enability of these tubing steels.

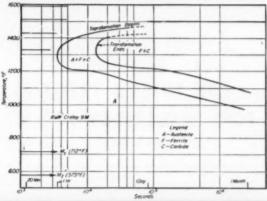
A technical report TR 520 covering the TTT tests and findings is yours for the asking.

CONDENSED DATA

B&W Croloy 7 and B&W Croloy 9 Tubing B&W CROLOY 7 (7% Cr., 0.50% Mo.)-For operating conditions where excellent corrosion resistance to hot oils is primary consideration. Has good oxidation resistance and high temperature strength to 1250 F. B&W CROLOY 9 (9% Cr., 1% Mo.)-Offers very good corrosion and oxidation resistance with good high-temperature strength to 1300 F. It is particularly suitable in refinery applications where sulphide corrosion is encountered. Good resistance to steam oxidation to 1100 F. Particularly suited for hydrogenation processes.

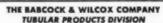


111 Curse for B&W Croley 7. Australized 40 min. at 1860 f As quenched grain size, AST M. No. 4 to 5.



III Curve for BOW Crolog 9 M. Amsternized 40 min. at 1860 1 As queuched grain size ASTM No The S

Both of these intermediate alloys have gained wide acceptance for giving optimum service satisfaction with economy in oil refineries, and petro-chemical, chemical processing, and hydrogenation plants. They're worth investigating. You'll find Mr. Tubes—your local B&W Tube Representative—a good man to consult on any problem involving alloy, stainless or carbon steel tubing.



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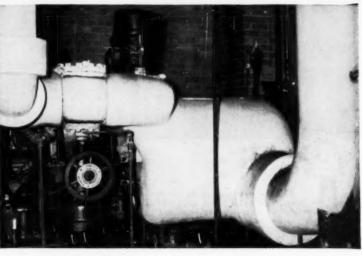
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TA-14985

For this new addition to their New York City power plant at East River and 14th Street...



(Above) View of recently completed annex to Consolidated Edison's power plant...another link in their gigantic expansion program. (Right) Close-up of J-M 85% Magnesia Insulation on boiler feed lines. It was expertly insualled by the Ashestos Construction Company, Inc., an outstanding J-M Insulation Contractor.

CON EDISON SPECIFIES J-M 85% MAGNESIA PIPE INSULATION FOR MAXIMUM FUEL SAVINGS

Like all materials that went into the new power plant addition of New York's leading gas and electric supplier...the pipe insulation had to be the best. That's why Consolidated Edison Co. specified J-M 85% Magnesia...industry's No. 1 insulation for many decades and still the leader in its class.

J-M 85% Magnesia is the leading insulation on the market for temperatures up to 600F. It is bonded with asbestos fibers. This rugged insulation will not distort regardless of the length of time it stays in service. J-M 85% Magnesia fits snug and stays put. Heat savings, therefore, remain constant for the life of the equipment on which this insulation is applied.

For temperatures over 600F, J-M 85% Magnesia is used in combination with Superex®, a J-M insulation for service to 1900F. This double-layer construction, known as Superex Combination, eliminates through joints and protects the jacket against scorching. It also utilizes the higher *Reg. U.S. Pat. Ogf.

heat resistance of Superex next to the hot surface, and the greater insulating value of J-M 85% Magnesia for the outer layer.

Experience has proved that all insulations must be properly installed to pay maximum dividends. That's why Johns-Manville offers industry the services of experienced insulation engineers and installation contractors who have made a career of solving complex insulation problems. From coast to coast, these engineers and the contractor's highly skilled mechanics stand ready to combine their talents and give you an insulation job that will more than pay off your initial investment with maximum fuel savings through the years.

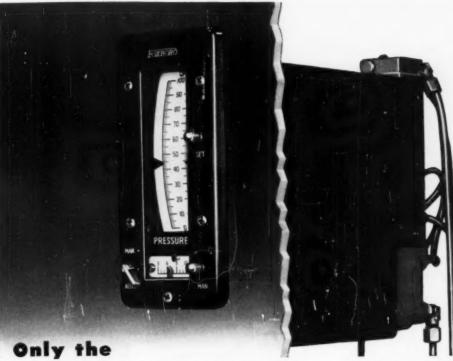
When you face your next insulating problem...remember that Johns-Manville is "Insulation Headquarters." Consult your near-by J-M Insulation Contractor... or write direct to Johns-Manville, Box 60, New York 16, New York. In Canada, write 199 Bay Street, Toronto 1, Ontario.



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CONSOTROL M/52

gives you all these advantages!

For indicating control functions in your console or graphic panel instrumentation, no other controller offers so much for so little money as the Foxboro Consotrol M 52 Indicating Controller. Compare these combined advantages:

- A completely self-contained, compact, panel-mounted Indicating Receiver Controller that costs up to 20% less, installed, than usual graphic panel indicating control.
- 2 Simple installation only 2 connections besides the air supply.
- Pull-out feature that provides complete accessibility of control mechanism from front of panel.
- Instrument-type pressure transmitter for driftless remote manual control, instead of usual pressure regulator.
- Simple 2-position transfer switch and "foolproof" transfer indicator provide absolutely bumpless transfer.

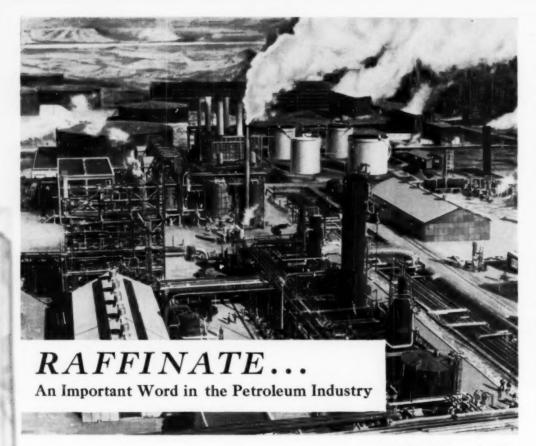
- 6. Graphic panel compactness takes only 3% of panel space.
- "Full-size" performance control action unsurpassed by the finest conventional-size controllers. Available in Proportional, Proportional with Reset, Proportional with Derivative, Proportional with Reset and Derivative, and On-Off.
- May be used with separately-mounted recorder using conventional circular charts. Up to 6 records may be combined on one chart with the Foxboro Multi-Record Recorder. (Consotrol Recorder-Controllers, featuring full scale 4" strip charts, also available.)

Get full details of this space-saving, cost-saving instrumentation. Write for Bulletin 463 describing the complete Consotrol Line of graphic panel instruments. The Foxboro Company, 3312 Neponset Ave., Foxboro, Mass., U. S. A.

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INSTRUMENTS



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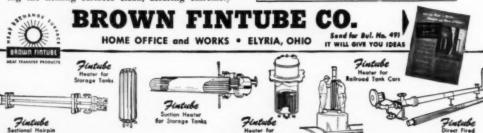
Brown Fintube Thermo-Flo Tank Heaters are more efficient, and usually cost less plus their installation, than the cost of just installing equivalent capacity of old fashioned bare pipe coil in the bottom of the tank.

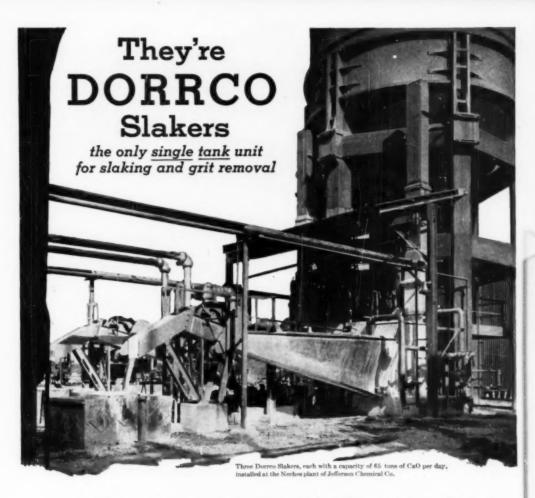
Brown Thermo-Flo heaters mount vertically, on adjustable legs about 12" above the tank bottom, thus preventing depositing on the tubes; and avoiding the lost efficiency of heating the tank bottom, and a layer of sediment. The bottom of the tank is uncluttered and easy to clean. The entire surface of the fintubes is exposed to the tank contents. Material adjacent to the fintubes is heated quickly and rises rapidly, forming a thermal syphon or flow past the fintubes; keeping the heating surfaces clean; assuring extremely

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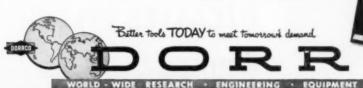
Large unit capacity because mechanism and tank design produces rapid hydration.

Quick installation at low cost...your Dorrco Slaker

is shipped almost completely assembled, requires no field welding, no costly piping installation.

Low maintenance costs...because all bearings are above solution and 1" thick white iron liners in the slaking compartment are designed for quick and inexpensive replacement.

Bulletin No. 7281 gives you more information about the Dorreo Slaker, its compactness, its simplicity and its durability. A copy of Bulletin No. 7281 is yours for the saking. Write for your copy today. THE DORR COMPANY, BARRY PLACE, STAMFORD, CONN.



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Here's what we meant by





A survey by a Dicalite Engineer enabled this manufacturer to cut filteraid usage by 663/3% per gallon of throughput

One of the many products in this manufacturer's line is varnish. It was being filtered by precoat only, using 100 lbs. of filteraid to deposit on the cloths of a 200-sq. ft. plate and frame press before starting to filter each 1000-gal. batch. A survey by a Dicalite engineer led to saving both time and filteraid. First, a switch was made to a higher-flowing grade of Dicalite filteraid. Only 25 lbs. of this material (Dicalite 4200) was used for the precoat, but 75 lbs. were used in continuous addition to the varnish as it was being filtered. In this way 3,000 gallons were filtered with satisfactory clarity before the press needed cleaning. RESULT: 1) 100 lbs. of Dicalite filtered 3,000 gallons instead of the 1,000 gallons put through by the former method; 2) cycle length was tripled, so that two press cleanings were eliminated in filtering 3,000 gallons and saved considerable down time and overtime. Such spectacular savings are not always possible, but our engineers find many cases where filteraid consumption could be reduced 10% to 15% without any ill effects to operation or product quality. If you feel that a check of your filtration operation or stretching your available supply of filteraid will be helpful, or if you have a current filteration problem, write our nearest office. A Dicalite engineer will gladly call at your convenience.

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Opinion and comment

PRIVATE ENTERPRISE AND ATOMIC POWER

WHEN one considers the future development of power from atomic reactors, it is almost certainly to envision a government monopoly in which industry has no voice or investment. Yet, the editorial mind perceives that the economic climate in America regarding the role of private companies in the nuclear field is slowly changing. Not long ago the National Industrial Conference Board held a two-day meeting on atomic energy in industry, and for two days a variety of speakers on a variety of subjects explored every possible angle of the great mystery of atomic energy.

Perhaps the most enlightening attitude of all was the fact that the businessman of today is setting up his own nuclear energy divisions, and he does not concede that industry is forever barred from the atomic energy program.

The attitude is perhaps best explained in a remark made by John S. Sinclair, president of the Conference Board, when he said, ". . . some power companies now regret the fact that in the early thirties they did not undertake flood control for a fee, for the government, selling the power developed by the dams, as a separate item." Business today is anxious not to allow the opportunity in atomic energy to slip by. Even now, private compaines are studying the possibilities of power.

During the conference, a fascinating story was told by George R. Prout, vice-president of Nucleonic and Atomic Projects for the General Electric Co. He said that with no more knowledge than that of 1946, 300 million dollars would have had to be spent in order to attain present levels of the original atomic energy plants at Hanford. However, research immediately was put to work on the problem and the phenomena that had threatened to end the useful life of certain of the original plants. The result was that these Hanford plants, instead of being shut down in 1949 owing to a particular type of threatened failure, are still producing and at substantially higher rates than originally intended. The anticipated replacements never became necessary. The same business type of mind is responsible for the fact that production has increased at all of the atomic energy piles, while costs of producing plutonium have been reduced materially.

While it is technically possible for power to be developed from nuclear piles even today, it is not, at present, competitive with other fuels. But before big business or any business can deal itself in, many things

must be clarified. As David E. Lilienthal, the first commissioner of the Atomic Energy Commission, stated in his talk before the conference, "The McMahon Act needs basic rewriting since at present it is hurting development." He further said, ". . . business in the atomic energy field should be allowed to apply to this development the same standards of security that are now applied to other military items. As things are now constituted," said Lilienthal, ". . . a businessman would not be justified in investing his own money in atomic power plants. Not only would they be supplementary to our present power developments, and not revolutionary, but their association with our military security program would be so close that the two could not be separated."

What the future holds in store is not at all clear. As of now, the electric power industry looks upon uranium as another source of heat energy and treats the production of electric power in much the same manner as it does its producing from coal. Whether or not scientists will be able to develop, by some as yet unknown principle, the direct production of electrical energy from radioactive disintegration, is in the future. Such a development is not only a great unknown but one that would, if efficient, make immediately obsolete most of the present ideas of power development.

Today we must place our hope for atomic power in the breeder-type reactor which creates more fuel than it uses. If a breeder-type reactor cannot be used, the conventional nuclear pile is perfectly satisfactory, provided, of course, that the government has need for the plutonium produced. Should the military demand for plutonium cease, then the nuclear pile would be uneconomical for power production, and efficiency would demand the creation of breeder-type power plants.

The technical problems involved are immense, and the A.E.C. is making headway in their solution. But the happy thought that comes out of the conference is not only that American industry considers itself qualified to enter into a nuclear program, but also that its philosophy is such that it is looking forward to such developments with eagerness. This eagerness is based on the full expectation that industry has the genius, the scientists, and the capital necessary to make this new technological development part of the free-enterprise structure of the United States.

F. J. VAN ANTWERPEN

TYGON

Versus CH, COOH

OMBATTING the attack of acetic acid has long been a problem to plant designers, process engineers, and maintenance men. Virtually all of the usual corrosion-resistant materials have been tried, but few have proved completely successful. Even the family of TYGON plastic compounds with its unusual versatility and chemical resistance is not the complete answer. However, with proper use, TYGON can, and does, give economical, enduring protection against acetic acid in many instances.

Essentially, TYGON consists of polyvinyl resins carefully modified with other materials to give the optimum in chemical and physical properties. However, because of its organic nature the resistance of TYGON to acctic acid varies according to the specific compound and physical form used and the conditions of exposure. In some cases, TYGON has failed. In many more cases, TYGON has done a job no other material could do. The key to success of TYGON against acetic acid lies in the use of the right compound and the right compound and form lies in consultation with U. S. Stoneware engineers.

For instance, as a press-polished sheet TYGON is used to line or cover tanks, drums, hoppers, bins, blowers, impellers, fume hoods and fume ducts. In such uses, TYGON resists acetic acid, in concentrations up to 15% by weight, at temperatures as high as 165-175°F. With concentrations greater than 15%, the temperature limit drops to 150°F. However, these limits may change according to the conditions of a specific application. Particularly does the use of acetic acid with its anhydride, other acids, or certain solvents make a difference. In addition, the TYGON compounds used in lining work usually are not recommended, because of toxicity, for use with foods. Thus, it is wise to consult a qualified engineer.

With TYGON sheets that are die-cut and used as gaskets, advice on chemical resistance is less essential. Because of the small exposed area of a gasket, TYGON can be used with acetic acid in any concentration and at temperatures up to 200°F. However, certain conditions such as high pressures or use with foods warrant consultation. A molded gasket

reinforced with glass fibers may be needed to handle the pressure, while a gasket of a nontoxic TYGON compound must be used for food.

When using molded TYGON as gaskets, grommets, washers, stoppers, handles, bumpers, or special fittings, concentration of the acid is not a factor and temperature limits again range as high as 200°F. Advice is suggested, however, on design of the piece, on questions of toxicity, and on use with other chemicals.

In extruded form, TYGON is used primarily as tubing or piping although extruded solid cord, channel and tape are also used as gasketing and coverings. As an extrusion, TYGON resists acetic acid in any concentration and at temperatures up to 200°F. Where tubing is used as flexible connections, as transfer lines, as ports on acid pumps, or as syphon hoses, engineering advice usually is not necessary because of the number of standard formulations and sizes (up to 2" ID) available. However, in work with constant pressures of more than 40 psi or mixtures with other chemicals, braided jacket reinforcement or other precautions may be needed and consultation is suggested.

As a paint, TYGON is used to protect all types of equipment, structural steel, walls and ceilings against the fumes and spillage of acetic acid, but only under mild conditions. The physical limits of a thin film prevent the recommendation of TYGON Paint against fumes and spillage of high concentration and at elevated temperatures. In all uses with acetic acid previous tests are suggested.

As a plastisol (TYGOFLEX), TYGON finds use as a heavy duty coating and in the casting or "slush" molding of flexible parts and fittings. As such, its resistance to acetic acid varies according to the thickness of the TYGOFLEX involved, but usually is comparable to that of gasketing.

Although its use against acetic acid is approached rather conservatively, as compared to its use with other chemicals, TYGON can provide long lasting and low cost protection. Its flexibility, toughness, abrasion resistance, and in some cases, clarity, permit its economical and advantageous use in many applications.



In addition to TYGON in its various forms, we also manufacture a number of other materials capable of handling acetic acid in any concentration and under all types of operating conditions. These products include chemical stonewave and porcelain, acid proof brick and cements, homogenous lead linings, and other organic linings and coatings.

Why don't you submit your corrosion problem today? There's no obligation and we'll be pleased to be of assistance. So write, now!

THE UNITED STATES STONEWARE CO., Akron 9, Ohio

ENGINEERS, MANUFACTURERS, ERECTORS OF CORROSION-RESISTANT EQUIPMENT SINCE 1865

High-Vacuum Concentration: Its Realm in the Chemical Industry

This paper deals with reduction of corrosion and scale problems as found in concentration processes in the chemical industry. It portrays physical, as well as thermodynamic, design of equipment and centers on operating pressures in the evaporator of about 10 mm. abs. This range of pressure and temperature is treated to show the reduction in corrosion by virtue of temperature reduction. It also treats the reduction of scale formation by lowering of temperature and pressure and it investigates the possibility of material substitutions due either to corrosive properties or to strength of materials.



E. J. Kelly

E. J. Kelly, manager of the concentrator department of Carrier Corp., Los Angeles, has been engaged in heat-transfer applications and design since his graduation from the School of Mines and Metallurgy of the University of Missouri. Formerly with Lummus Co., and then with Graham Manufacturing Co., both of New York, Mr. Kelly, in the 1940's, moved to California, where he developed a high-vacuum concentrator on the falling-film principle which was purchased by Carrier Corp. in 1947.

THE chemical industry has always been faced with two major problems, which are predominant in concentration processes. The first is corrosion; the second, scale-forming liquors.

The cost of corrosion is constantly being reduced by the chemical industry through improvements in construction materials and in processes. The latest improved process is higher vacuum concentration

Many concentration problems, considered high-vacuum operations, have for some time been conducted under vacuums in the range of 100 mm. abs., but high-vacuum concentration herein means concentration at pressures in the range of 6 to 15 mm. abs.

Since most of the material being removed in everyday concentration is water, reference to pressures as low as 6 to 15 mm. abs. signifies saturation temperatures in the range of 40° to 64° F. Operation at these temperatures presents a number of problems to the designer.

All evaporation processes must have a condensing medium colder than the vapor that is evaporated. When, therefore, evaporation as low as 40° is considered, the first big problem is where to obtain condensing medium at a reasonable cost. Allied to this problem is, of course, that of corrosion and scale formations.

Design of Concentrator

Figure 1 shows a cross section of the evaporator used in conjunction with high-vacuum work. It is called a falling-film concentrator because the liquor to be concentrated is recirculated from the bottom of the concentrator to the top and films down the inside of large-diameter tubes so that the tubes are not completely full of liquor. Rather, there is only a film presented to the heating surface, or the tubes, of the concentrator.

The unit is a conventional vertical heat exchanger consisting of a shell, tube sheets, tubes, inlet channel, and separation chamber. The inlet channel is at the top and the separation chamber at the bottom, because with the falling-film design both vapor and liquid travel down the tubes into the bottom vapor separator. The advantages of this design will be discussed later. This type of construction, coupled with a refrigeration unit, composes essentially a heat-pump cycle.

Cycle of Operation

A flow diagram and heat balance are shown in Figure 2. To get the colder condensing medium is the primary function of the refrigeration machine. However, it is not economical to use a refrigeration machine solely for producing

chilled water. It is preferable to have the refrigeration machine furnish the heating source, as required in all evaporation problems, as well as the cold source. Figure 2 shows that the refrigeration machine supplies chilled water to a condenser, either a barometric or surface type; the temperature of this chilled water as it exits from the condenser allows pressures to be maintained in the 10 mm. abs. range. In other words, the pressure maintained on any evaporator is dependent upon the leaving temperature of the condensing medium. This discussion deals with water being chilled; however, for even lower absolute pressures, brine may be substituted for water, or a refrigerant may be directly substituted in a surface-type condenser. Thus the condensing temperature, or the pressure maintained on the system, could be considerably lower than that represented herein.

to the condenser, and so the refrigerant vapor in being compressed can then be condensed with ordinary tower water or other water supply. The heat that is given up by the chilled water to the refrigerant is transferred to the condensing water in the refrigerant condenser. If this water is piped to the evaporator as heating medium, a heatpump cycle will be completed-but by means of heat exchange and specificvolume exchange rather than by direct vapor compression. It is interesting to note that this particular heat balance is what would be experienced for 100 lb./ hr. of water evaporated.

The heat-transfer figures in Figure 2 show that the only uneven balance is in the mechanical work done in compressing the gas or in the motor horsepower required to drive the compressor. From a heat-rejection standpoint, therefore, when about 100,000 B.t.u./hr. is trans-

cal property most important is the boiling-point rise. In general, in evaporators there are two hoiling point rises: first, that due to the chemical properties of the material itself and, second, that due to hydrostatic head in the evaporation equipment. Reference to Figure 1 reveals that the boiling-point rise due to hydrostatic head has been eliminated in the falling-film design because there is no liquid level maintained in the tubes. Here, then, consideration must be given only to the boiling-point rise as a chemical property of the liquor to be concentrated. If this phenomenon imposes too great a temperature difference across an evaporator, it can be combated in a number of ways, e.g., by staging concentration or by higher temperature differences across the evaporator itself. The flow sheet (Figure 2) shows that the temperature difference across a given evaporator is not great enough,

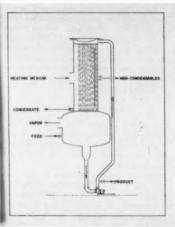


Fig. 1. A falling-film concentrator.

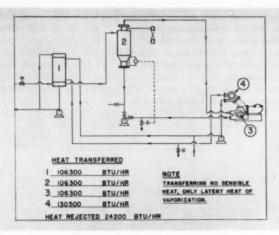


Fig. 2. Flow diagram and heat balance.

It can be seen that the vapor evaporated from the evaporator is condensed in the condenser, giving up its heat to the chilled water. To make a true heatpump cycle, it should be possible directly to compress the water vapor itself. In present mechanical equipment this possibility is circumvented by the large specific volumes of low-pressure water vapor. When the vapor is condensed in the chilled water, the chilled water then exchanges this heat with a refrigerant, and thus not only heat, but specific volumes have been interchanged, so that the refrigerant specific volume is in the realm of mechanical compression. To follow the cycle through therefore, the refrigerant vapor is compressed while the water is chilled for its return trip ferred, only about 25% is rejected. By this balance it can be immediately seen that the single-effect evaporator on a heat-pump principle is equivalent in economy to a quadruple-effect evaporator. The evaporator shown in Figure 1 combines therefore with a refrigeration machine to make up the apparatus shown in Figure 2, a high-vacuum concentrator whose temperature limitations need be only those imposed by process requirements.

Boiling-point-rise Considerations

In the inherent design of an evaporator or concentrator, physical properties of the liquid to be concentrated are also of extreme importance. The one physiespecially for those materials having a high boiling-point rise as concentration progresses. With a centrifugal type of compressor, however, turbine drive rather than motor drive can be adapted to the compressor and the steam exhausted from the turbine to the evaporator as heating medium. This will not increase water or steam requirements over a conventional quadruple effect.

Insofar as boiling-point rise is concerned, evaporator design does not present a material problem in the handling of organic liquids, because in general organics have a low boiling-point rise. The high-boiling-point-rise liquids are predominantly salts. When a solution of salts is concentrated, a great deal of care must be taken to allow for this boiling-point-rise phenomenon. High vacuum will reduce the boiling-point rise of a given material.

Corrosion, Its Relation to Temperature

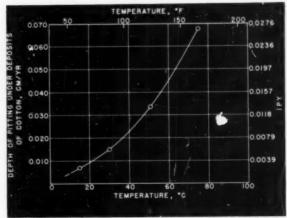
From a corrosion standpoint it is basic that as temperature decreases, corrosion rate decreases. Figure 3 exemplifies the statement; it does not portray a common magnitude of corrosion. The curve shows the rate of corrosion on mild steel in a salt solution of a given concentration where corrosion rates are plotted against temperature. It can be seen that by reducing temperatures from 60° to 20° C. the corrosion rate falls from 0.045 to 0.010 cm./yr. In other words, corrosion at 20° C. is about 25% of what would be present at 60° C., which indicates that corrosion can be seriously dealt with by reducing temperature. To reduce temperature, pressures must be lowered, or high-vacuum concentration achieved.

Corrosion. Its Relation to Velocity

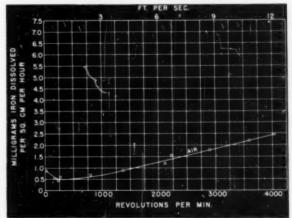
Corrosion is also accelerated by velocity. It varies with velocity in the same way that it varies with temperature. An increase in velocity increases corrosion rate. Decrease velocity, and corrosion rate will decrease.

Conventionally, in concentrators and evaporators as used today, the risingfilm and/or forced-circulation concentrators are the most common. In either of the evaporators mentioned above, the trend has been to reduce capital cost by increasing velocity, thereby giving higher heat-transfer rates and less heattransfer surface. It has been found, however-especially on highly viscous material-that the heat-transfer rate of a falling film is comparable to that in either of these types of evaporators. This was demonstrated as far back as 1888, when Lillie invented the fallingfilm concentrator (1).

The falling film therefore was investigated from a corrosion standpoint. Figure 4 shows the amount of iron dissolved per hour at various velocities, with the liquor being circulated in air. In other words, there is no other component in the test that might reduce the corrosion rate, which is shown in relation to velocity. It can be seen that by reducing the velocity from about 9 to 3 ft./sec., the corrosion rate is also reduced to about 25% of that experienced at the higher velocity. In the falling-film concentrator the fall of the material down the tube answers the call of gravity, minus the frictional resistance. Thus the velocity is not high, but the heat-transfer rate for a given velocity is correspondingly higher because of the thin film presented to the heating surface. Cor-



Courtesy of John Wiley & Sons, Inc.
Fig. 3. The effect of temperature on corrosion.



Courtesy of John Wiley & Sons, Inc. Fig. 4. The effect of temperature on velocity.

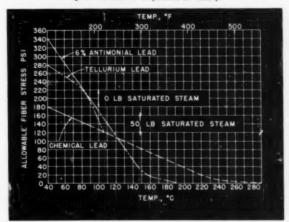


Fig. 5. The effect of temperature on the fiber stress of lead.

rosion, therefore, has been reduced in two ways: first, by a reduction in temperature and, second, by a reduction in velocity. Judging from the magnitude by which corrosion is reduced for a specific process, it is feasible that materials of construction might be changed to less costly ones than now used. Or, if this is not possible, the corrosion allowance as commonly made could be reduced and the attendant heat-transfer rate of the evaporator increased directly proportional to the reduced resistance offered by the metal wall. Thus capital savings, if not made by material substitution, certainly could be made by reducing the amount of material, both by the elimination of corrosion allowance, and by a higher heat-transfer rate, which, in essence, means less heat-transfer sur-

Structural Advantages at Lower Temperatures

Consideration also has to be given to what the lower temperature may do from a structural standpoint. In many chemical processes lead is the accepted material of construction. Lead, however, is not one of the stronger metals. The usefulness of lead falls off very rapidly with an increase in temperatures. Figure 5 shows allowable fiber stress plotted against temperature. From this curve it can be seen that chemical lead will have an 80% increase in allowable fiber stress when temperatures are decreased from 130° to 40° C. It is possible therefore that in some instances where lead heretofore has not been used for structural reasons, it may become desirable as a material of construction if temperature levels of operation are reduced.

Lead in this case is only an example. Time and further experimentation will show whether or not other materials have the same failing. Certainly, ceramics might fit the picture.

Consideration of Scale in Highvacuum Concentration

Aside from corrosion, the other nemesis of the chemical industry is scaleforming liquors. Most of these form scales because of some calcium or sodium salt in solution. These calcium and sodium salts having, for the most part, inverted solubility curves, solubility decreases as temperature increases, and scale forms on the heat-exchange surface.

With these inverted solubility substances it is readily seen that if temperature is reduced more material will remain in solution and therefore will form less scale. Possibly in some processes scale may be eliminated, but certainly for all processes the lower the

temperature, the greater the reduction in scale formation. Scale formation is costly to the chemical industry—probably just as costly as corrosion—not from the standpoint of replacing equipment, but from the standpoint of efficiency during operation, as well as of lost time due to descaling operations. As in the case of corrosion, it has been found that the falling-film concentrator can also reduce scale formation.

Perhaps one of the largest scale problems in concentration today is in the concentration of black liquor for the pulp industry. In this case, the main scaling component is calcium sulfite.

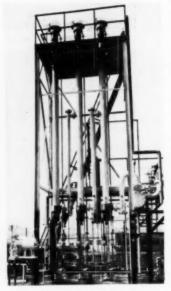


Fig. 6. Pilot plant of triple-effect design.

This, fortunately, has an inverted solubility curve, but in experiments conducted it was desired to find whether or not the falling-film concentrator had any benefit other than that offered by temperature. It was found in concentrating black liquor from 10 to 50% solids at 100° C., that on the falling-film concentrator, scale built up very slowly and operation could be sustained for periods of 60 or more hours with only a slight decrease in heat-transfer capacities; whereas with conventional equipment, such as rising-film or forced-circulation types, decrease in heat-transfer capacity was significant at the end of 24 hours of operation.

More surprising than these results was the discovery that the scale formed

was a soft scale and could be removed surprisingly well by merely washing with water; whereas the scale found in the other types of evaporators was hard and had to be mechanically removed. This formation can be accredited to the lower temperature difference across the metal wall, coupled with lower film temperatures and a washing of the heattransfer surface at all times (2).

Also to be recognized is the fact that with exposure of only a thin film to the beating surface there is very little superheating of the liquid. The film is almost uniform in temperature.

Converse to that, where tubular equipment has the tubes full of liquid, to bring the center portion of that liquid to a desired temperature it is necessary to superheat the film adjacent to the wall of the tube, and thus a preponderance of scale is in evidence.

Again, it is seen that by a combination of the falling-film concentrator and lowtemperature or high-vacuum concentration, scale is materially reduced and descaling operations are minimized.

Amount of Heat-transfer Surface Presented

Probably an immediate reaction to combating scale and corrosion with high-vacuum concentration is that because of the lower mean temperature differences used in the evaporators there will be a subsequently greater surface presented for whatever scale or corrosion may exist. This objection might be valid had the whole cycle not been incorporated into a heat-pump cycle. In other words, it is true that lower temperature differences mean greater heat-transfer surfaces, and certainly in cycles such as presented above the temperature differences are lower than conventional; but where a single-effect evaporator, coupled with a heat pump, shows the economy of a quadruple-effect evaporator, it does not have as much surface as does the equivalent quadruple effect.

This phase is particularly important from a capital-investment standpoint in that it is cheaper to build one piece of equipment than four pieces; also, if scale and corrosion were equal in magnitude, corrosion would require maintenance or replacement of only one piece of equipment, and shut-downs due to scale removal would be of shorter duration because it would be easier to clean one piece of equipment than four pieces. To take this characteristic a little further, an organic compound that does not have a high boiling-point rise may be considered. Many installations have been made where the heat-pump cycle has been applied to a triple-effect concentrator, and the total temperature drop across this triple effect was only 65° F. Again the objection may be too much surface, but from an economic standpoint, a triple-effect evaporator—when operating in a heat-pump cycle—has the economy of nine effects. The problem of corrosion and/or scale is certainly easier to combat in three effects that it would be in nine, and perhaps in any other particular case the economy derived would more than offset the cost of corrosion or scale correction.

Experimental Results

Most of the discussion in this paper has been on general terms, primarily because most of the development work in the chemical field has been done only on pilot-plant scale. The pilot plant used to conduct these experiments is shown in Figure 6. It is of triple-effect design and is a prototype of many of the evaporators now installed for the concentration of citrus juices. Being a triple effect, it permits studies and observations at various temperatures while essentially one experiment is being conducted. The design temperatures of operation are 75° F. in the first effect. 62° F. in the second effect, and 50° F. in the third. These temperatures are variable either up or down with the subsequent change in capacity. However, capacity was considered secondary to the experimentation that has been done.

Earlier it was suggested that highvacuum concentration could conceivably allow the use of less expensive materials of construction for a given process. One such process where this is evident is in the concentration of caustic soda. Caustic soda is one of the salts with an extremely high boiling-point rise in the high range of concentration. At about 50% caustic soda has approximately a 64° F. boiling point rise, and thus it circunivents the axiom that low temperature accompanies high vacuum. However, this is a much lower temperature than any experienced in present-day equipment or process.

In those industries where iron free caustic is desired, the savings in high-vacuum concentration cannot be realized, but where nickel today is normally used for caustic soda evaporation caustic soda has been concentrated to a 35% solution in the high-vacuum pilot plant. Caustic embrittlement, the main corrosion problem, did not arise because even at the 35% concentration and its boiling-point rise the temperature of the solution was not in excess of 150° F.

In industry it is conceivable that caustic soda can be concentrated in mild-steel rather than nickel evaporators up to a concentration of 35% and then transferred to a finishing evaporator to bring the concentration up to 50%. The

only reason for a transfer is that as 50% concentration is approached, the boiling-point rise is so great that the liquor temperature is high enough to allow caustic embrittlement of mild steel. Here is an evaporator, however, that is only one-fourth nickel, where conventionally it is four-fifths nickel. As stated above, this advantage is not useful where iron free caustic is desired, as in the rayon industry.

Another serious corrosion problem that has been experimented with is in the concentration of magnesium chloride solutions at elevated temperatures where the solution tends to break down and liberate gaseous HCl. Corrosion-resistant materials must be used conventionally because of this breakdown of the liquor. With high-vacuum concentration, the temperatures are such that this breakdown, and subsequent release of gaseous HCl, is eliminated. Thus materials of construction for this process do not need the serious consideration that they presently receive.

Two examples of scale formation that have been experimented with are black liquor and brine. For black liquor, as mentioned before, where calcium sulfite is the scaling agent, what can be learned by pilot-plant methods shows that down time for scale removal could be reduced by 50%. This, coupled with the fact that the scale that is formed is more easily removed, definitely indicates a usefulness for high vacuum as a means to keep the equipment on the line (2). In concentration of brine, the main scale former is calcium sulfate, which in conventional concentration methods separates as a hard scale. It begins to form almost as soon as the evaporator is put into operation and continues at such a rate that at least once a week the evaporator must shut down and scale be mechanically drilled out of the tubes (3).

With high-vacuum concentration, not only is the scale formation reduced, but whatever scale does form is a softer scale that is easily washed away. Thus again down time for scale removal is lessened, because high vacuum permits longer sustained periods of operation as well as shorter scale-removing time.

Conclusion

High-vacuum concentration, therefore, has its place in the chemical industry because with it corrosion can be
minimized, materials of construction
may be subject to review, and the problems of scale formation can be materially lessened. It is not to be construed
that high-vacuum concentration must be
applied only with a falling-film concen-

trator. High-vacuum concentration may be applied with any type of concentrator provided it is properly applied. The falling-film concentrator, however, aids high vacuum and its possible role in combating corrosion and scale.

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- Badger, W. L., and Baker, E. M., "Inorganic Chemical Technology," 2nd ed., McGraw-Hill Book Company, Inc., New York (1941).

Discussion

- L. E. Hilbert (Carbide and Carbon Chemicals Co., South Charleston, W. Va.): Have you had any difficulty in securing uniform distribution of liquids in the falling-film evaporator?
- E. J. Kelly: On a properly screened or filtered liquid we have not had any. Difficulty has been encountered where the liquid being concentrated has undissolved solids in process—something that would plug up the distribution system. With the amount of material processed we have no set method of distribution. We generally experiment with many types of distribution before deciding on one particular type for any given process.
- L. E. Hilbert: Would you care to comment on any particular type of distribution method that you use?
- E. J. Kelly: Distribution has been one of our great sources of difficulty in using the falling-film evaporator. The most common type of distribution that we have used consists of the perforated plate above the tube sheet. It is mandatory that the top tube sheet be absolutely level and that the tubes be ground flush with the top of the tube sheet. About 34 in, above the tube sheet, we put in a perforated plate with properly sized holes so that the flow through these holes will hit the diamond of the tube layout. When it hits the diamond, there are about six holes around each tube; and after hitting the diamond, it flows into the tube. The important point is the top head-or the head above the distribution plate-must be small enough so that a constant head may be maintained above the perforated plate; so actually a little pressure is put on to get it down to the tube sheet and make

VACUUM FACILITIES

For the Study of Supersonic Flow

THE role of the wind tunnel as a basic tool of the aerodynamicist has long been recognized in the history of American aviation. The need for such test facilities to guide the development of aircraft capable of extreme high-altitude flight has recently become apparent (16). The simulation of the flow conditions for such extreme high altitude flight has, however, not always been possible. With the present availability of large commercial vacuum-pumping equipment capable of high-capacity lowdensity gas flows, the vacuum engineer can proceed to design and construct a suitable low-density wind tunnel to simulate flight conditions which may be found at altitudes from 40 to 60 miles or higher. The design, construction, and operation of such test equipment has been carried out during the past six years by the department of engineering at Berkeley in a program originally sponsored by the Office of Naval Research and now sponsored jointly by the Office of Naval Research and the Air Research and Development Command.

It should not be construed from the above emphasis on wind tunnels and high-altitude flight that the efforts of this group or the experience gained applies to aerodynamics only. The investigation of the characteristics of critical nozzles in low-density gas flows (6) is an example of a program of interest to workers in the field of vacuum engineering. Problems associated with the design of vacuum structures, whether they be wind tunnels or stills, always require an understanding of structural design and sealing techniques. Instruments used to measure pressures in a low-density wind tunnel can be used to measure other pressures of low magnitude. Problems of all large integrated vacuum systems are similar; hence, it is the purpose of this paper to describe the development of one such system as a source of information to other workers in the field of vacuum engineering.

Preliminary Considerations for a Low-density Flow System

The evolution of the largest low-density wind tunnel now used at Berkeley resulted from experience gained in the construction of two smaller units (4). The choice of an open-circuit, continuously operating flow system was primarily dictated by the characteristics of the various vacuum pumps that were considered. Inasmuch as all jet pumps (oil, steam and mercury) and positivedisplacement pumps exhaust a characteristic vapor together with the working fluid, it was considered essential to use an open-flow circuit. Complexity of instrumentation, especially time-response considerations, led to a preference for a continuously operating unit rather than one of intermittent opera-

The demand requirements of a nozzle to produce a supersonic jet with a uniform test area of 2 to 4 in. diam. indicated that flow rates from 3 to 100 lb./ hr. would be necessary at pressures from 30 to 300 µ Hg, respectively. With such flow rates a nozzle could be designed to produce a sufficiently large uniform supersonic jet for test purposes at pressure levels equivalent to those found from 40 to 60 miles in the atmosphere. Comparison of the above-mentioned demand requirements with the performance characteristics of various vacuum pumps indicated that a five-stage steam ejector (Croll-Reynolds, 20-in. diam. inlet) would provide a satisfactory economical drive unit (7).

A secondary independent pumping system is necessary to:

- Provide preliminary evacuation of the tunnel volume preparatory to ejector pumping.
- 2. Maintain a base pressure low enough for "gage zeroing."
- Provide an easily adjustable means of varying the tunnel pressure for gage calibration.
- Provide a pumping means to allow sensitive leak-hunting methods to be employed.
- 5. Maintain the tunnel system under vacuum conditions prior to a test to minimize "outgassing" effects upon pressure measurements.

The choice of the pumps to be used for such purposes is primarily dictated by an estimate of the allowable in-leakage of the final unit plus the contributions of an adsorbed gas layer within the structure and the vaporization of relatively volatile materials which are required in the vacuum system. An example is given (1) of specifications for a vacuum unit used in a gaseous-diffusion process which further analyzes the probable in-leakage contribution of various elements that make up the final unit. Taking into account the larger number of access ports and tubular pressure-gage lead-ins into a wind tunnel, an arbitrary rate of pressure buildup of 12µ Hg/hr. for a wind-tunnel volume of 300 cu.ft. was chosen as a goal for vacuum fitness. A base pressure of 10-8 to 10-4 mm. Hg was chosen as suitable for gage-zeroing purposes. The unit chosen to perform this function consisted of a 20-in. (Distillation Products Inc.) oil diffusion pump, a 6-in. (DPI) booster pump, and a 5-hp. (Kinney) mechanical pump. This combination has a volumetric capacity of 4000 1./sec. (141 cu.ft./sec.) at 2×10^{-4} mm. Hg.

Design and Construction Details

Structural Design. The principal stresses imposed upon the shell of a low-density supersonic wind tunnel are due to an external atmospheric-pressure load. The design of the structure of the No. 3 Wind Tunnel (Fig. 1) was governed by the A.S.M.E. Code for unfired pressure vessels with external pressure. Results as obtained from the code tables were adjusted to provide heavier sections to insure adequate rigidity for instrument mountings and to prevent possible handling damage to thin removable access ports. Cylindrical and spherical shapes were used wherever possible. Standard dished heads were em-



G. J. Maslach

George J. Maslach is currently directing research on low-density gas flows and flow visualization at low-pressure levels for the Low Pressures Research Group at the University of California Institute of Engineering Research, where he is supervising engineer. After receiving a B.S. degree from the University of California in 1942, he was employed in radar research, first as a staff member of the Radiation Laboratory of the Massachusetts Institute of Technology and later, from 1945 to 1949, as senior mechanical engineer at the General Precision Laboratory, Inc., where he remained until he assumed his present position.

ployed as accèss ports to the test area. Large, 20-in. diam., one-inch thick, glassviewing windows were provided to permit constant visual inspection of instrumentation mounted within the test area. Hydraulically operated clamps were used in place of threaded fasteners to allow a rapid removal of the dished heads to permit ready access to the test area. The test chamber and upstream stagnation chamber were mounted on roller supports to allow dismantling of the gasketed joints for inspection of the seal materials and also to provide for movement of the structure to accommodate thermal expansion.

Materials. In addition to the usual properties of strength and elasticity, certain additional vacuum characteristics of materials must be considered during the design of a low-pressure system. These characteristics are (1) the vapor pressure, (2) rate of evaporation, (3) porosity and (4) the sorption characteristics of the material under consideration. The importance of each of the above-named factors in any specific application depends upon the proposed operating pressures and temperatures. Knowing these requirements, each material to be considered may be investigated by the means given in (5). Requirements of the No. 3 Wind Tunnel, pressures of 30 to 300 µ Hg and atmospheric temperatures, did not require that great emphasis be placed on the choice of materials for the structure. The choice of material for pressure instrumentation leads and small high-impedance lines however, was carefully considered as will be shown later. Inasmuch as no great emphasis was placed upon choice of structural materials for the No. 3 Wind Tunnel, no lengthy analysis of the vacuum properties of materials will be given here. A few comments on the properties of the common materials used will be included, however, as a qualitative guide.

Rolled or forged alloys of iron, aluminum, and copper were used in the fabrica-tion of the No. 3 Wind Tunnel. For reasons of economy, strength, and ease of fabrication, low-carbon steel was used as the major structural material. Cast products were not used for reasons of porosity. The use of copper alloys containing a high percentage of zinc was restricted to areas where high-pumping speeds prevailed. Such materials were not used in pressure-measuring lines which have a high flow impedance. The formation of oxides and hydroxides on the surface of steel, iron, and copper requires special consideration. These layers are highly hygroscopic and take up moisture upon exposure to atmospheric conditions. The later removal of this moisture by diffusion is a long and difficult process and such a problem is to be avoided. especially in units having a restricted pumping speed. To improve materially the vacuum performance of iron and copper alloys, low-vapor pressure paints or var-nishes were used as protective coating applied after a thorough cleaning of the metal surfaces. The oxide film for aluminum is not hygroscopic, and further the vapor pressure of this film is lower than the parent material; therefore no special treat-

ment is necessary.

Nonmetallic materials are often required in vacuum systems. Such materials used in the No. 3 Wind Tunnel are glass, quartz, various plastics, and rubber compounds. The use of glass was limited by fabrication considerations to relatively small components. Plastics were used to an extent limited by their thermal properties. Rubber was widely used for sealing purposes inasmuch as the operating pressures were

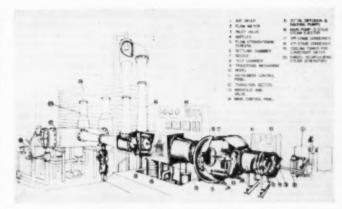


Fig. 1. Law-density supersonic wind tunnel

greater than 1µ Hg. The use of rubber must be carefully considered as the vapor pressures of various compounds are high and vary considerably.

Construction Techniques. Following the selection of suitable materials for a vacuum system, methods of iabrication must be considered to insure minimum in-leakage. In most vacuum systems the greatest contribution to in-leakage comes from fixed and gasketed joints, Disregarding, for the present, gasketed joints, which will be treated later, several comments can be made regarding fixed joints to insure minimum in-leakage.

Gas or are welding was used on the structure of the No. 3 Wind Tunnel and proved to be a safe, convenient method of providing rigid sealed joints. Normal precautions were taken to produce slag-free gas welds and strong penetrating are welds. Single-pass continuous welds were emphasized and, when necessary, overlaps were generous and based on a cleaned previous weld. Almost all welds were on the outside of the structure. Double welds, inside and outside, on a single seam were always avoided as the enclosed pockets could provide an endless source of virtual leaks which would be difficult to detect. Structural welds were of an intermittent type and did not pass over a sealing weld, again to avoid formation of virtual leaks.

The successful use of shielded arc welding to join aluminum and stainless steel indicated that for future work greater use of these materials should be encouraged. Other methods of joining metals such as brazing or soldering were used and similar precautions were observed. Structural limitations of soft soldering along with the fact that soldering alloys contain high percentages of zinc limited the use of this joining method. An account of the general problems associated with vacuum vessel fabrication has been presented (8) together with examples of various preferred welding techniques.

Gasketed Joints. The design of almost any vacuum structure must provide gasketed joints either for purposes of assembly or for access to the interior of the unit. The choice of the gasket material and the design best suited for each application must be determined by the vacuum requirements and operating conditions. Ordinary synthetic and natural rubber compounds have been employed as gasket materials for the No. 3 Wind Tunnel. Both round and square cord and standard "O" ring continuous gasket forms have been used. Manufacturers' recommendations have heen closely followed to insure that the proper groove dimensions and chamfered edges are provided. The standard practice at Berkeley has been to allow for 30% diametral deformation of a gasket when used in a flange joint and 10% deformation for seals movable both in translation and rotation. Often a seal may be provided with a method to allow adjustment of the deformation.

Three examples of "O" ring seals used in the No. 3 Wind Tunnel may be of interest. The measurement of static and impact pressures over an area of a stream requires a movable probe system with a pressure lead-out to a fixed sensitive element. A traversing mechanism capable of motion in three directions is used to cover the desired area. A rotary probe mount located on the traversing mechanism allows any one of eight probes to be inserted in the stream at one time. Three important seals were designed to provide a conduit from the probe to the sensitive element. They consist of (1) a movable flange seal which is positioned against the base of the probe in use, (2) a translation seal within a telescoping tube, and (3) sealed ball-and-socket joints located to accommodate the movement of the traversing mechanism.

The first joint seal, a movable piston with a flanged-type "O" ring gasket, is raised and lowered into position opposite any one of eight ports located on a rotating probe mounting block. The camactuated motions of the piston prior to and following the movement of the rotary member protects the ring seal from any shearing actions which would occur as the various ports passed by. Chamfering a port to prevent tearing or cutting the gasket often is

not possible because of space limitations and the above technique provides a successful solution. A second seal between two closely fitted small-diameter telescoping tubes is an example of the use of a standard piston-cylinder seal. The tubes, well sup-ported to insure minimum bearing loads on the seal, can be extended several feet to accommodate motions of the traversing mechanism. The third example, the use of an "O" ring in a ball-and-socket joint, is essentially a type of piston-cylinder seal except that the mating surfaces are spher-ical. A threaded cap has been used for ease, of assembly and to permit adjustment of the degree of seal ring deformation. These three seals, occurring in a pressure-measurement circuit, have provided years of reliable service. Periodically the joints are inspected and subjected to leak detection but to date no evidence of failure has been noted.

Metallic gaskets have been used in applications where operating temperatures have been excessive for nonmetallic materials, for example, in flange seals of oil jet pumps. Soft copper and aluminum are common materials for this service. A nonmetallic material Teflon has been successfully employed in a number of instances. Its use is mentioned here for the reason that an undesirable characteristic of this material, "cold flow" or creep, is normally associated with metallic gaskets. Ingenious designs, where pressure loading is continuously applied to insure maintenance of a mating surface, can often overcome this undesirable characteristic. The extremely low vapor pressure of this plastic material is a prime reason for its vacuum use.

Vacuum Performance

The final appearance of the No. 3 Wind Tunnel is shown in Figure 1 where the scale of the unit can be estimated by using the 60-in. diam. dished heads on the test chamber as a basis for comparison. Initial flow tests indicated that a satisfactory jet could be generated at the proper pressure levels. An initial pressure build-up of 30 m Hg/hr. has been reduced by persistent leak detection to a value of 10 µ Hg/hr. This value is considered satisfactory inasmuch as there are more than eighty electrical leads and thirty instrument connections into the vacuum system in addition to many large gasketed and welded joints. It is recognized that this pressure build-up is not all due to inleakage. Measurements of the pressure build-up are normally made at a base pressure of 0.1µ Hg where one can expect to feel the influence of the vapor pressure of various elements in the system. Several motors and many plastic components undoubtedly contribute to the pressure build-up.

Experience derived from several arduous leak-detecting campaigns indicates that a prime consideration of design, often forgotten, is to provide suitable means of testing each gasketed joint. Nothing is so disturbing as knowing a leak exists in a complicated integrated structure and that no straightforward test can be made to check a dubious joint. Hidden joints or blocked

channels should always be avoided. If possible, means should be provided to isolate sections of the system to permit detailed leak detection. Pressure-measuring lines and gages should always be checked as independent units before incorporation into a system.

Instrumentation

Investigations to determine the fundamental nature of fluid flow and heat transfer in a rarefied gas stream require a knowledge of various quantities such as impact pressure, static pressure, gas velocity, Mach number, temperature. and density. Force measurements are of interest also to determine lift and drag coefficients for various basic shapes. Typical completed programs are presented (3, 12, 11) which were concerned with heat-transfer measurements, drag-force measurements, and pressure measurements. By far the greatest instrumentation effort has been placed upon the measurement of pressures. The measurement of a pressure in a flowing gas or at some point on the surface of an object submerged in the gas involves consideration of at least three distinct problems: (1) the pressure-sensitive element, (2) time response and gage geometry and (3) the external flow. The nature of each of the above problems will be amplified in the following sections.

Pressure Sensitive Elements, Operation of the No. 3 Wind Tunnel requires sensitive elements suitable for measurement of pressures less than 10 mm. Hg with especial emphasis upon pressures between 0.01 to 1 mm. Hg. A complete review of the wide variety of pressure-measuring elements that are commercially available is given in (5). An analysis of many of these elements indicates that they are physically unsuited for aerodynamic measurements, or that they are not capable of yielding consistent results to an accuracy of 1µ Hg at a pressure level of 100 µ Hg. This conclusion has led to a preference for a "primary-standard" type of instrument suitable for wind-tunnel work,

Two such instruments have been developed, a precision differential manometer (14) and a precision McLeod gage, shown in Figures 2 and 3. The unique features of the manometer are contained in the optical method of viewing enlarged images of the meniscuses and the precision screw, gearing, and differential system that presents the differential height, in inches, directly on a counter. This height can be measured precisely to 0.0005 in, or approximately 1µ Hg. The manometer has the advantage over other primary standards in that a continuous monitoring of a pressure can be maintained. The small volume of the instrument reduces the time-response considerations as will be shown. Although the manometer is considered a "primary standard" it has been noted that for extremely precise work a calibration is necessary.

using a McLeod gage as the standard. This variation in the manometer characteristic has been correlated with changes in temperature and is believed caused by a change in the specific gravity of the low-vapor-pressure manometer fluid, butyl phthalate. The performance of this instrument over a long period indicates that the mean scatter of points about the calibration curve is $\pm 0.7 \mu$ Hg.

The successful use of a precision gearing and counter assembly to determine the height of a column has been utilized in the construction of a precision McLeod gage. Here optical elements are again utilized to view the meniscus. This instrument was designed for a program requiring a precision of 0.1% at 30µ Hg. The performance indicates that such a precision can be attained; however, to date no means of checking the theoretical precision of this gage has been available. Based on an analysis of the least count of the instrument, it appears reasonable to expect a precision of at least 0.2% at 30µ Hg with better performance at higher pressures up to 900µ Hg.

The manometer described is used for all pressure measurements from 20 mm. Hg down to 0.1 mm. Hg when ±1% accuracy is desired. The McLeod gage is used from 0.1 mm. Hg down to 0.01 mm. Hg but only when ±1% accuracy or better is required.

Experience with commercial Piraniand thermocouple-type gages has indicated that the range of usefulness of these gages depends upon many details of construction, circuiting, and ambient temperature control. The solution of all such detailed problems can be achieved; however, no permanent solution has been found to the basic problem of control of the thermal emissivity and accommodation coefficient of the wire which appears to change with time and with the previous history of, the gage. Since a wind tunnel must be opened periodically for model changes, past history effects



Fig. 2. Precision differential manameter.



Fig. 3. Precision McLeod gage.

result in great variations of gage performance during the relatively short run periods. Calibration of these gages daily is a long tedious procedure and must be repeated before and after each test. In view of these considerations, Pirani-type gages have been used mainly to indicate relative vacuum conditions rather than to provide precise pressure measurements.

Recently the use of extremely small impact pressure probes was investigated with the pressure-sensitive element mounted in the body of the probe. The element used was a "thermistor manometer," a type of Pirani gage. The performance of this unit indicates that small Pirani-type gages can be successfully used where space and volume considerations are paramount. Advantages of small size plus the fact that the electrical output of the gage permits direct recording of measurements will undoubtedly extend the use of Piranitype gages for such applications.

Time Response and Gage Geometry

The problem of time response in a pressure-gage system and the effect of "outgassing" on pressure measurements have been analyzed (15). This analysis is based on free molecular flow, e.g., at pressures sufficiently low so that the molecular mean free path is larger than a typical gage-system dimension. At higher pressures, where the flow is viscous rather than free molecular in character, such calculated time constants will be conservative.

The work at Berkeley has often required that the smallest possible probe be used to measure a stream pressure.

This size limitation has been determined in the following manner. The time constant, that time it takes for the gage system to register 1/e of its complete change following a sudden change in pressure, is calculated from the analyses of (15). A system is designed, varying the dimensions of the probe or lines, to arrive at a time-constant value of several seconds. Experience has shown that a period of several time constants must elapse for a system so designed to reach a complete pressure equilibrium. A check of the design is made prior to the use of the probe by timing the response of the system to a pressure charge induced by releasing a trapped volume of air into the wind tunnel. It is possible that a probe might have so high a flow impedance that a false equilibrium pressure will be indicated. This false pressure is the result of "outgassing" which may be of greater magnitude than the pumping speed of the probe system. Figure 4 is an example of the behavior of a number of probetype pressure measuring systems used for an experimental program similar to that reported in (11). It can be seen that for these systems at least 180 sec. must elapse after a pressure change before a true pressure reading can be noted.

External Flow

The problem of external flow arises in the measurement of static and impact pressures in supersonic and subsonic structed at Berkeley to study unique problems of flow and heat transfer in rarefied gases. Although each unit was designed for a special function, all units have in common the requirement of good vacuum performance. A brief description will indicate qualitatively the operating conditions and the functions of the various equipments.

Molecular Beam—Model 2. A molecular beam apparatus (Fig. 5) has ocen contructed, operated and used to develop techniques and instrumentation to permit study of momentum and energy transfer phenomena at a gas-solid interface, (9). The design of the equipment allows a base pressure of 10-4 mm. Hg to be achieved. The pressure build-up of the entire system is approximately 1/5µ Hg/hr. Special ionization gages and amplifiers have been constructed to measure pressures during the various experimental programs that have been scheduled. By means of a combination of two gages, a detector and a comparator, pressure differences of 10-4 mm. Hg can be detected on a base of 10-4 mm. Hg. The equipment has been used to verify experimentally the Clausing theory of molecular flow through short tubes (10) and is being used at present in a program where an attempt will be made to measure the accommodation coefficient of various gassurface interactions.

Rotating Cylinder. A high-speed rotating cylinder (Fig. 6), which operates in a chamber where the pressure can be controlled to levels less than 10⁻⁴ mm. Hg has been constructed and operated at Berkeley, The vacuum requirements of this system are similar to those given for the No. 3 Wind Tunnel. A torque balance has been designed to operate remotely in the chamber and to register the drag induced by a

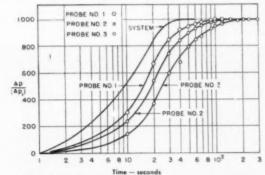


Fig. 4. System time response following a sudden change in pressure.

flows of a low-density gas. Here the behavior of the probes no longer follows the conventional pitot tube formulae. Deviations from these common concepts are treated (11, 13), but it should be noted that such departures from ordinary gas dynamics are possible and predictable in low-density flows.

Other Experimental Equipments

Several other experimental equipments have been designed and conrotating cylinder upon a concentric floating cylinder. Results of an experimental program using this equipment, aimed at determining the reflection coefficient of a gassurface interaction, is reported (2).

Summary

Large-scale aerodynamic test equipment which simulates high altitude flight conditions can now be designed and constructed. Choice of materials, fabrication methods, and gasketing principles must be guided by both conventional

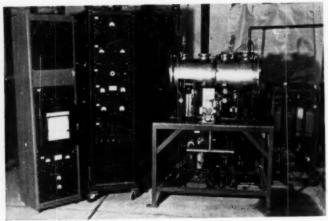


Fig. 5. Molecular beam apparatus.

strength and ease of manufacture principles and also the principles of vacuum engineering. Precise pressure measurements, such as are required for aerodynamic investigations, can be insured by using "primary standard" types of instruments. Experimental results that have been obtained to date, especially those pertaining to instrumentation developments, are of interest to all fields of vacuum engineering.

Acknowledgments

The various facilities described are the results of the efforts of many men over a period of several years. The various programs have been carried out under the supervision of Prof. R. G. Folsom, E. D. Kane and S. A. Schaaf of the department of engineering at the University of California at Berkeley. Other major contributors during this period have been D. O. Horning, F. C. Hurlbut, R. A. Evans, F. S. Sherman, and R. R. Cyr.

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Discussion

- E. W. Flosdorf (F. J. Stokes Machine Co., Philadelphia, Pa.): What is the reproducibility of readings with the butyl phthalate manometer?
- G. J. Maslach: In the use of the manometer over a period of more than one year we have been able to reproduce pressure readings with a scatter of less than ±0.7 Hg. These reproduction data come from our calibration of the manometer using a McLeod gage as the primary standard. Although the manometer is a primary standard itself we have discovered that the specific gravity of the manometer fluid changes with temperature, requiring occasional spot calibrations to determine the correct manometer constant. The change in specific gravity of butyl phthalate is approximately 1% for every 10° F. change in

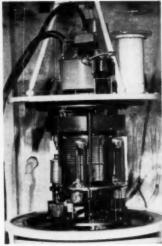


Fig. 6. Rotating cylinder equipment.

temperature. You can see, therefore, that the calibrations are necessary only for extreme precision in the pressure measurement.

- R. A. Denton (Optical Film Engineering Co., Philadelphia, Pa.): I am interested in the rotating cylinder device which is described. We have a similar rotating problem and would like to know the power necessary to spin a large piece of metal in a vacuum. Can you tell me how much power was required to spin your rotor at 25,000 r.p.m. in your vacuum chamber and did you make any rotational tests at higher pressures? If you made other tests what differences of power would be necessary for the high-pressure rotational case?
- G. J. Maslach: The drive unit for the rotating cylinder device is a purchased item produced by the Specialized Instrument Corp. in California. This drive is equipped with a 3 hp. d.c. water-cooled motor. I am not sure of the exact power requirements at 25,000 r.p.m., although I do know that this motor will spin the rotor at higher speeds in our vacuum system. We have just completed an experimental program using this equipment as part of a Ph.D. thesis in engineering. In this thesis the man actually measured the induced torque in a concentric torque balance which surrounds the rotating eylinder. This measurement was taken at various pressure levels from one micron up to several hundred microns mercury. It may be that you will find the information that you are looking for in this thesis. We plan to report this work as a project report in the near

(Presented at A.I.Ch.E. French Lick Meeting.)

RECENT DEVELOPMENTS IN PROCESS INSTRUMENTATION

J. PROCOPI and S. D. ROSS

Minneapolis-Honeywell Regulator Company[†], Philadelphia, Pennsylvania

I T is difficult to summarize recent developments in process instrumentation strictly in terms of new-product descriptions. Rather, one must study control philosophy as practiced by chemical and process engineers, instrumentation engineers, and instrument designers and manufacturers in order to obtain a clear concept of what is happening in process instrumentation.

What are some of the existing trends?

- 1. Centralization of control with its emphasis on elimination of the problems of (a) lags attendant to long transmission distances, (b) confusion of operators who had to memorize the functions of scores of instruments, all similar in appearance, and (c) large size and cost of central control because
- 2. Segregation of important data through scanning and monitoring.
- 3. Direct product quality control with less dependence on inferential measurements.
- Recognition of servomechanism techniques in the application of instruments to processes.
- 5. Incorporation of computer techniques into process control.

Looking Backward

A review of progress in instrumentation provides a helpful perspective and, therefore, a greater appreciation of the current trends.

Instrumentation history reveals three distinct eras of advancement:

- 1. Accounting and recording
- 2. Automatic control
- 3. Present transition

As a result of the impetus supplied by World War I, mass-production techniques and continuous processing emerged early in the 1920's. Cost accounting, a mass-production must, required better tools than the then-employed hand-counting methods. Fluid flow meters and continuous weighing equipment, which provided quantity records on a 24-hour-day basis, became

an intimate part of practically all processes.

Therefore, by 1930, an estimated 14,000 American manufacturers were employing industrial instruments in their plants. This accounting and recording era witnessed early researches into automatic control, fostered by an ever-increasing complexity of processing technology. Even with reliable information continuously at hand, the shortcomings of manual operation were becoming apparent.

By the mid-thirties, instrumentation was looked upon as a necessity in meeting quality and cost requirements. The number of users rose to 18,000. Technologically, industrial instrumentation entered the automatic control era. It was found that on-off control could not handle all of the processing problems, Proportional, proportional - plus - reset, and other more sophisticated modes of control were developed to keep pace with

the growing advances and complexities of processing techniques.

World War II and its feverish industrial aftermath bestowed upon the instrument industry, a role of vital importance. Orders for instruments today stem from more than 40,000 users and, it is estimated that by 1954, the total will become 90,000.

Considering each of the five trends mentioned previously in this paper: the first is Centralization of Control.

Centralized Control. In the years that immediately followed the emergence of continuous processing, locally mounted indicating and recording constrollers were employed to regulate process variables. These locally mounted instruments failed to achieve the automatic coordination that was required for optimum efficient operation. Early attempts to effect closer supervision and better coordination took the form of locally mounted panelboards. The next

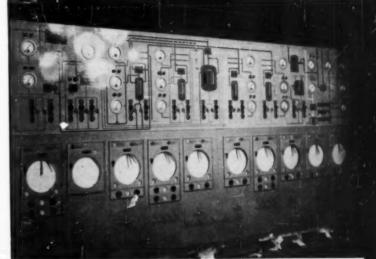


Fig. 1. Semigraphic panel.

[†] Brown Instruments Division.

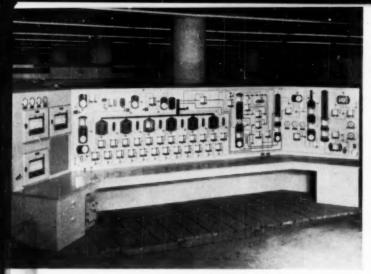


Fig. 2. Full graphic panel.

step was a grouping of these individual panelboards into one control board which was mounted in a centrally located control room.

With processing increasing in size and complexity, the number of instrution of instrution of the point where control panels became large and unwieldy. Operator training time increased.

Perhaps the most serious problem was that of lags attendant on long transmission distances.

In order to improve over-all process supervision and to minimize the confusion resulting from over-large panelboards, many attempts had been made years before to effect a graphical representation of the process on the control board.

Out of the period of gradual development which followed emerged the graphic panels as they are known today.

In one type of panel, the semigraphic, only small dial-type industrial instruments are placed in the flow diagram. Miniature recorders and controllers, as well as those of conventional size, are mounted below and alongside the diagram. Colored symbols are employed on the instruments and in the flow diagram, in order to indicate the points of application. (Fig. 1.)

Contrasted to this method of instrumentmounting is the full graphic panel which utilizes miniature recorders and indicators mounted directly in the flow diagram. In this type, as in the semigraphic panel, use of color is important in keeping streams identified. (Fig. 2.)

Development of Panel Components. Concurrent with this graphic-panel activity has been the development of industrial-instrument components that permit close-coupled control systems, thus resulting in a minimum of transfer lags. The merits of close-coupled systems have been established for processes where measurement and control lags are small. Thus, in a flow installation, a newly developed blind controller is placed adjacent to the process or on the valve yoke. In this manner, the advantages to be gained from the small measurement and control characteristic time are not cancelled out by long transmission lags, which occur when the controller is distantly removed from the

In this development the controllers are mounted on the reverse side of the panelboard. This method of installation is employed usually where trans er lag is a small part of the total lags of the system, such as is usually the case in temperature control.

On the front of the board, miniature recorders and indicators are mounted in the flow diagram corresponding to the points of measurement in the process. Units, such as miniature recorders which mount on 6-in. centers, provide a continuous record of the process variables. By means of knobs and switches, the control valve air-pressure loading and set point can be obtained, or an operator can switch from automatic to manual operation and back to automatic, without upsetting the process. (Fig. 3.)

Advantages of Graphic Panels.

Many advantages result from the use of graphic panels. It is generally agreed that graphic panels effect a reduction of panelboard space and of the size and cost of a control room. In addition, plant operating personnel, with little prior knowledge of the process being controlled, are appreciably aided in following flows, with the result that operator training time is greatly reduced. Instrument downtime is decreased, a benefit made possible by the fact that these miniature instruments can be quickly interchanged.

Among other advantages which have been claimed for graphic panels are that they are easy to install and simplify start-up procedure. These economies should become more apparent with improved process instrument designs and as a better understanding of the panel is attained through its increased utility.

Segregation of Important Data. Dial and scanning systems are additional manifestations of the transition era. In a dial system, a manually supplied impulse starts a chain of actions that results in switching any desired measuring element of several hundred into a measuring circuit, so that the magnitude of the pertinent process variable may be recorded or indicated. In a scanner, a timed impulse replaces the manual one employed in the dial system. Indicating type-dial and scanning systems that are equipped with alarms are termed monitors" whereas recording types are referred to as "loggers."

Development of these systems stems from the fact that with increasing complexity and size of processing units, the matter of measuring and indicating hundreds of miscellaneous temperatures, pressures and other variables becomes cumbersome and unwieldy; space requirements for indicators and key switches become prohibitive.

The Sun Oil Co. recently designed a dial system. In order to check the temperature of a specific thermocouple, the operator simply dials three numbers. The system is arranged so that the next nine thermocouple points to the first thermocouple can be checked by simply adding one impulse at a time.

A scanner-monitor-logger has been designed in which a timed impulse, operating in conjunction with the recorder-printing mechanism, initiates a chain of action which automatically switches one thermocouple at a time into the measuring circuit. This switching action also energizes the "point" and "bank" lamp on the face of the control unit. (Fig. 4.)

In one particular unit there are nine banks of nine points each, or a total of eighty-one thermocouple points. Various switches in this unit provide flexibility in operation. Any bank may be recycled or omitted, as desired. Printing can be continuous, or, by simply throwing a switch, the instrument can be made to print only when the set point is exceeded.

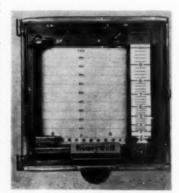


Fig. 3. Tel-o-Set miniature recorder.



Fig. 4A. Scanner-monitor-logger.

Direct Product Quality Control. Another significant trend in process instrumentation is in the direction of increased utilization of continuous analyzers in the control of petroleum and chemical product quality.

Proponents of product quality-control philosophy point to the numerous benefits attendant on its use, such as better control, improved equipment design, higher yields and an acceleration of research made possible through faster, more accurate analyses than are possible by current sample-to-laboratory inethods.

A mass spectrometer was recently installed at the Paulsboro refinery of Socony-Vacuum Oil Co. for continuous analysis of a deethanizer bottoms stream. Concentration of ethane was continuously and accurately recorded during a test period of several months duration. (Fig. 5.)

Similarly, infrared analyzers have been used to determine carbon dioxide content of flue gas of a fluid catalytic cracking unit and a host of other applications. Continuous density-recording mechanisms measure per cent conversion of monomers in butadiene-styrene copolymerizations. Continuous-testing dielectric constant meters determine the concentration of aromatics in a mixture of hydrocarbons, while continuous refractometers analyze the composition of olefins in a mixture.

Servomechanism Techniques. It is evident from the foregoing brief that it has been necessary constantly to consider improvements in control in order to keep abreast of technological expansion. The last decade has witnessed extensive engineering activity in a new approach to control problems called servomechanism techniques.

Answers to such questions as: (1) How far can I go in cutting plant construction costs by designing to take full advantage of automatic control? and (2) How much can the cost of operating the plant be reduced by such a design? lie in an exacting and comprehensive study of process control by a practical method which encompasses all facets of the problem—the process, measuring element, transmitter, the controller and valve.

Servomechanism techniques show much promise in answering such ques-

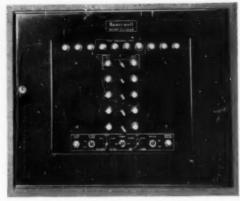


Fig. 4B. Control unit for scanner-manitor-logger.

tions. Perhaps the strongest point in favor of them, however, is that at present they offer the only practical solution to more complex problems, where other methods of control analysis and prediction fail.

What Are Servomechanism Techniques? To servomechanism engineers, the control problem involves a study of the dynamics of an entire system. This system-engineering concept embodies not only a consideration of the dynamics of the process, but also of the measuring instruments and control devices. These dynamics can be expressed mathematically over their entire range of behavior in terms of frequency response.

These frequency response curves have a sound theoretical basis and are easily manipulated by those who do not wish to delve deeply into mathematics. They are used to assist in selecting the type of controller required and to calculate controller settings required for efficient operation.

Computers. Coincidental with the increasing activity in servomechanisms is the tremendous development that is currently affecting computing machinery.

Large electronic digital computers are becoming increasingly more important with expanding engineering knowledge. The solution to more complex calculations can be reached with electronic aids, thus relieving the engineer of this time-consuming function.

Digital computers, for example, can be used quickly and accurately to make difficult calculations required in designing distillation towers for multicomponent systems. Other engineering calculations related to design of unit operations such as absorption, extraction, and drying causimilarly be effected on computers of this type.

Computers eventually may play a significant role in automatic control. Of course, present-day pneumatic control.

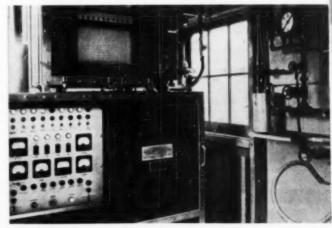


Fig. 5. Cantinuous analyzer.

lers are computers, and more specifically, analog computers, by definition. However, as the name implies, the function or physical quantity operated on is analogous to the original signal, and as such is related only indirectly to the actual dynamics of the process being controlled, and to quality factors in the product. As discussed earlier, servomechanism techniques supply the answer to the question of how to tie in the dynamics of process and instruments. The computer, on the other hand, may be the means of bringing quality control into the loop.

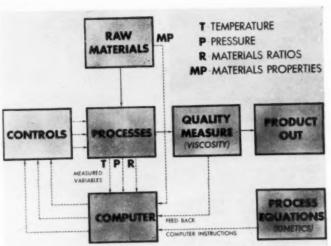
A suggestion has been made as to how this may be accomplished. Product viscosity, which is closely related to product quality, is measured and returned to the control loop. Process variables of temperature, pressure and ratio of materials are controlled by conventional instruments. The computer is used to interpret the quality measure in the light of process dynamics, and in turn, establishes regulation over the various process variables. (Fig. 6.)

Written Discussion

J. Johnstone, Jr. (Du Pont Co., Wilmington, Del.): Mr. Procopi has presented a clear exposition of the changes which have occurred in the use of instrumentation during recent times. We endorse his hope for attainment of fully automatic processing within the fore-seeable future. There are, of course, many areas in chemical plant operation in which this would not seem economically appropriate, nor even possible.

Certainly the recent trend away from a renfused array of instruments, row on row and all alike, is a welcome one. At a stepchild of centralization, the great number of indicating dials and instrument charts located close together had reduced comprehension and increased the already confusing complexities of modern chemical processes.

The advent of miniature instruments permitting the design of engineered graphic control boards has gone far toward simplification. In several large plants the idea of console operation has been extended to provide fully integrated and interlocked control of complete segments of the process. First efforts in that direction sometimes resulted in temporary failure. Several factors contributed to this, but the main shortcoming has seemed to be lack of appreciation on the part of the specifying engineer for the instrument requirements. We have learned that the most important aspect of instrument components in integrated systems is their adaptability. The misapplication of instruments occurs most frequently because of inadequacies under the proposed conditions or inability to accom-



Courtesy Chemical Engineering

Fig. 6. Proposed method for bringing quality measure into the control loop.

modate the broad range of operating requirements. For example, the flame failure device applied to combustion safeguard equipment may not be adequately protected against the effects of moisture or chemical corrosion, or, alarms which are inadvertently energized by vibration or other extraneous effects do not provide reliable signals. Measurement devices which are susceptible to ambient error provide unreliable readings, and control valves with unsentiable characteristics make for strange results.

The proper evaluation of factors contributing to instrument inadequacy under expected circumstances requires instrument engineering knowledge. Manufacturers have done much to implement provision of such knowledge and still further progress seems to be promised in the form of frequency response analysis. It is to be hoped that measurement and control components will be described in these terms in the near future. Many instrument users have undertaken a program of education on this subject. Investigations conducted along these lines have produced new information about instruments which previously were thought to be fully known. Our ability to evaluate this information is not yet complete but a formal program to improve this situation is well under way.

The main deterrent to the acceptance of monitoring systems has been the inflexibility of standardized versions. The system illustrated in this paper would appear to overcome much of this objection. Every application of monitoring which we have encountered has involved custom-built arrangements necessitated

to accommodate the operational requirements. One of these units has a maximum capacity of more than 3000 points which are scanned in an elapsed time of 10 min. Each of these variables must be separately identified with a particular section and subsection of the process, and the associated alarm system, recording means, and manual selector must be suited to these requirements. The monitoring idea is somewhat handicapped then by the varieties of custom-designing required by instrument customers.

Quality control, in the sense that a critical property of the end product (such as viscosity) is used to guide the energy exchange or material balance of the process, still suffers from some practical shortcomings. Under plant conditions this instrumentation must be tailored to overcome an extensive range of sampling difficulties, measurement inadequacies, extraneous interferences, and finally it must be built to withstand the possible mishandling by installation and repair technicians. The announcement of the availability of such new scientific technique is still well ahead of its acceptance as a practical control tool under field conditions. Progress toward realization of practical acceptance requires close cooperation between maker and user. This calls for willingness on the part of the maker to provide the features which are adaptable to specific applications, and on the part of the user to open the plant door in order to promote comprehension of the conditions under which newly developed apparatus is used.

(Presented at A.I.Ch.E. Atlanta (Ga.) Meeting.)

FLUIDIZATION OF SOLID PARTICLES IN LIQUIDS

E. W. LEWIS and ERNEST W. BOWERMAN

Humble Oil and Refining Company, Baytown, Texas

A NUMBER of experimental investi-gations have been made of the characteristics of the fluidized bed, including liquid-solid and vapor-solid systems of both batch and continuous operation. Lewis, Gilliland, and Bauer (3) have presented a limited amount of data on the batch fluidization of fine uniformsized glass spheres in water in the lower regions of flow resistance and have correlated their data by several methods. Wilhelm and Kwauk (6) have presented a large amount of data on batch fluidization for larger uniform-sized solids and have correlated their data with a family of curves using a form of friction factor. However, it is desirable to have a consistent method of correlation that would define the bed behavior-flow characteristics relationship of liquid-solid batch fluidization systems throughout the entire range of flow resistance as encountered in chemical engineering practice. Also, since most solid catalysts used industrially utilizing the fluidized-solids technique are not of constant diameter, it is desirable to gain an insight into the difference between the fluidization characteristics of uniform- and nonuniform-sized solids. The program undertaken and reported herein was directed toward these ends. Since 3.4 cracking catalyst contains particles having a wide variation in size and since this material has been used in much of the work involving fluidization with gases, it was chosen for the study.

Stokes' Law Region

Batch Fluidization of Powdered 3A Catalysts with Upflowing Liquid Hydrocarbons. In discussing the phenomeenon of the fluidization of solid particles by means of upflowing liquids, consideration must be given first to the free settling of a solid particle

Original data (Tables 1-10) are on file (Document 3671) with American Documentation Institute, 1719 N Street, N.W., Washington, D. C. Obtainable by remitting \$1.00 for microfilm and \$1.65 for photoprints. Flow characteristics for batch fluidization of fine nonuniformly sized solids in liquids have been investigated and compared with the results when constant diameter glass spheres are used in the same region of flow resistance (Stokes' law region) previously reported by other investigators. Data have been correlated through free motion considerations of these systems. In order to cover the entire range of flow resistance as encountered in chemical engineering practice, previously published results of batch liquid-solid fluidization systems in the Intermediate and Newton's law regions have been used to develop similar correlations; the combination of these correlations can be used to predict the performance of batch liquid-solid fluidized systems.

in still liquid. In the free-settling system, a particle falls under the action of gravity and accelerates until the frictional drag of the fluid just balances the gravitational acceleration, after which it will continue to fall at a constant velocity known as the terminal or free-settling velocity, $n_{\rm p}$. The terminal velocity for spheres in the region of laminar flow, characterized by values of the particle Regnolds number, $Re_{\rm p}$, up to about 2, is defined by the equation

$$u_t = \frac{gD_p^2(\rho_s - \rho)}{18\mu} \tag{1}$$

which is derived in detail by Brown, et al., (1) and is known as Stokes' law. In a liquid-solid batch fluidization system, above the point of incipient fluidization, the particles are accelerated upward until the gravitational acceleration balances the frictional drag, at which time the expanded bed of solids will remain at a constant height for a constant liquid velocity. However, although in the fluidized state the particles are separated from each other by at least film of liquid, there is mutual interference in the motion of the particles when many particles are present, and the velocity of the associated liquid motion is considerably less than that computed by the equation derived on the assumption of free motion of the solid particles. Since the mutual interference in the motion of the particles in the fluidized system should rapidly decrease with increased distances between particles, the steady-state liquid velocity through the fluidized bed can be related to the free motion of a particle by a factor which is proportional to a power function of the fraction voids, ϵ , in the fluidized bed of solids. This relationship is expressed by

$$u = u_t(k'\epsilon^{b'}) \tag{2}$$

where k' and b' are constants applicable to a particular system. However, assuming the effects of any horizontal velocity distribution to be negligible, the liquid velocity through the bed past the particles is equal to the superficial liquid velocity, u_n, based on the empty column divided by the fraction voids in the bed, and Equation (2) may be writ-

$$u = \frac{u_o}{\epsilon} = u_t(k'\epsilon^{b'}) \qquad (2a)$$

Substitution of the value of u_t from Equation (2a) into Equation (1) results in the expression

$$\epsilon = k \left[\frac{\pi_o \mu}{g D_p^2 (\rho_g - \rho)} \right]^b = k \left[K_a \right]^b$$
(3)

where k and b are constants. Equation (3) relates the fraction voids in a liquid-solid batch fluidization system in the Stokes' law region to the flow characteristics. This equation can be used to determine the height of a fluidized solids bed from the known physical properties of the liquid and solid and the superficial liquid velocity through the column, as the fraction void, which is not directly measurable, is calculated from the

height of the bed of solids by the equa-

$$\epsilon = \frac{hA_o - h_oA_c}{hA_c} = 1 - h_o/h \quad (4)$$

To test the relationship of Equation (3), experiments were performed in the batch fluidization of nonuniform-sized 3A cracking catalysts with upflowing liquid hydrocarbons. In these experiments column diameter, average diameter and density of the solid, initial bed height, and the viscosity and density of the liquid were varied over a range sufficient to prove the relationship of Equation (3). Superficial liquid velocity, pressure drop, and the height of the fluidized bed were measured. The re-

TABLE 2.—FRESH SA CATALYST, N-HEPTANE

$$\begin{array}{lll} D_g = 2.520 \times 10^{-6} \ {\rm ft.} & D_g = 3.70 \ {\rm cm.} \\ \mu = 2.45 \times 10^{-6} \ {\rm lb./(ft.) (sec.)} & h_1 = 18.6 \ {\rm cm.} \ (200 \ {\rm cc. \ cat.}) \\ T = 90^{\circ} \ {\rm F.} & h_2 = 10.6 \ {\rm cm.} \end{array}$$

h	. =	V	u_o	u _a	ΔP
cm.	$I - h_a/h$	ec./hr.	ft. nec.	$gD_{\rho}^{\circ}(\rho_{\theta}-\rho)$	$h_a(\rho_s - \rho)$
52 9	.8600	5020	4.26×10^{-3}	9.28 × 10-4	1.00
46.9	.773	3900	3.80×10^{-1}	7.23×10^{-3}	0.83
40.4	.737	2880	2.44×10^{-3}	5.34×10^{-8}	0.85
24.0	.558	112	9.40×10^{-5}	2.08 × 10-4	0.53
24.5	.567	300	2.54 × 10-4	5.56 × 10-4	0.85
23.7	.552	60	5.08×10^{-5}	1.12 × 10-4	0.38
23.3	.848	4.2	3.55 × 10-4	7.78×10^{-6}	0.20
37.2	.715	2220	1.86×10^{-3}	4.12×10^{-3}	0.80
44.4	.761	3800	2.79 × 10-2	6.11×10^{-1}	0.84
50.1	.788	4275	3.62 × 10-4	7.93 × 10 °	0.85
58.1	.817	6120	5.18 × 10-3	1.13×10^{-2}	0.92
68.5	,845	8520	7.21×10^{-3}	1.58×10^{-2}	1.00
96.8	.883	13000	1.10×10^{-2}	2.41×10^{-2}	
77.1	862	10635	9.00 × 10-8	1.07 × 10-7	

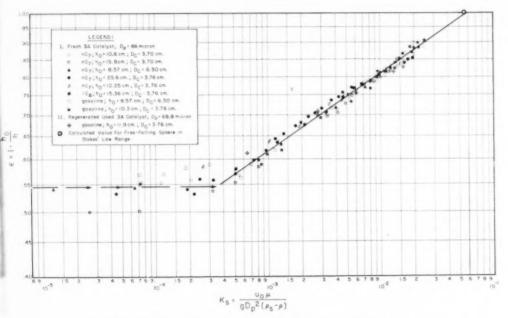


Fig. 1. e vs. K. for 3A catalyst-liquid hydrocarbon batch fluidization systems—Stokes' law region.

sults of a representative run are tabulated in Table 2, and the complete experimental results are illustrated in Figure 1 by the logarithmic plot of ϵ vs. the dimensionless group K_{κ} . The constants k and b of Equation (3) were evaluated by the method of averages for the continuous portion of the curve above the point of incipient fluidization, and the equation of this curve in Figure 1 is

$$\epsilon = 1.389 \left[\frac{u_o \mu}{g D_p^{-2} (\rho_o - \rho)} \right]^{0.1181}$$
(3a)

It is of interest that this curve extrapolates at 100% voids, where $u_0 = u_t$, to a value of K_s nearly equal to the value of 1/18 for the terminal velocity of a free-settling sphere in still liquid as defined by Equation (1).

Figure 1 also shows the curve to be discontinuous at a value of equal to 0.546, whereas the value of eq for dry fresh 3.d catalyst is 0.431. This difference is due to classification of the various-sized particles upon fluidization and removal of the fines from the interstices of the larger particles to the top of the bed. In connection with this classification of the various-sized particles

upon fluidization of the bed of solids, it was desirable to establish the effect of the particle-size distribution upon the expansion of the bed. Uniformly sized solids small enough to be in the Stokes' law region are not readily available, and little experimental work has been reported using these particles with liquids. However, Lewis, et al., (3) reported the results of the batch fluidization of 0.0061-in. diam. uniformly sized glass spheres with water and also the hindered settling of 0.0040- and 0.0061in. constant diameter glass spheres in water, the latter being simply the inverse operation of the former. A logarithmic plot of e vs. the calculated values of K, for their experiments together with the curve for the batch fluidization of 3A catalysts from Figure I is shown in Figure 2. It can be seen that there is considerable difference between the slopes of the two curves. the constant diameter systems in the Stokes' law region being represented by

$$\epsilon = 2.00 \left[\frac{u_0 \mu}{g D_p^{-2} (\rho_e - \rho)} \right]^{0.215}$$
(3b)

This difference in slopes is due to the difference in the particle-size distribution, as the smaller particles of a bed of nonuniform-sized solids will begin to fluidize and thus cause the bed to expand at a velocity lower than that required for the particles having the average diameter. Thus, to represent all liquid-solid batch fluidization systems, the correlation must include a parameter to take particle-size distribution into account. However, the performance of systems using nonuniform-sized particles can be accurately predicted from the equations for constant-diameter spheres. This can be done by using the equations to calculate the performance for each narrow fraction of particlesize distribution as determined by, for example, a sieve analysis assuming the arithmetic mean-particle diameter of the fraction to be the average. The performance of the entire system is calculated then as the weighted average of the results for each fraction.

Previous investigators have concluded that the pressure drop across a bed of fluidized solids is equivalent to the weight of the solids. The weight of the bed of solids, correcting for buoyancy, is $h_o A_c \rho_s - h_o A_c \rho = h_o A_c (\rho_s - \rho)$. The pressure drop measured across the entire cross section of the column is $(\Delta P)A_e$. If the pressure drop is equal to the weight of powder in a fluidized bed.

$$\frac{\Delta P}{h_o(\rho_s - \rho)} = 1 \quad (5)$$

In order to test this relationship, Figure 3 presents a logarithmic plot of $\Delta P/h_n(\rho_0-\rho)$ vs. K_s . On the abscissa K_x is used as the criterion of fluidization rather than liquid velocity because as shown in Figure 1, although the fluidizing velocity varies for different systems, K, is essentially constant at the point of incipient fluidization. Above this critical value of K, equal to 3.6×10^{-4} a horizontal line equal to unity on the ordinate should be obtained. The data show considerable deviation from this line, although a

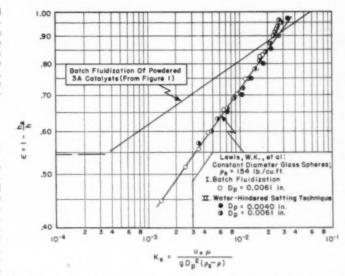


Fig. 2. Effect of particle-size distribution upon fluidization characteristics in Stokes' law region.

value of 1 is approached at the higher group $\Delta P/h_a(\rho_s-\rho)$ plotted against K_s values of Ko. However, it should be noted that presenting the pressure-drop data in the form of the dimensionless

correlates the experimental results on one curve both before and after fluidization is attained.

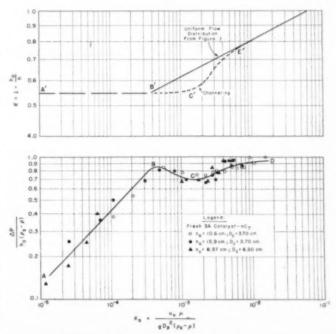


Fig. 3. Batch fluidization of powdered 3A crocking catalysts with liquid hydrocarbons.

Wilhelm and Kwauk (6) observed pressure-drop-velocity relationships for a bed of uniformly sized particles in an upward flowing stream of water of a pattern identical to the plot of $\Delta P/h_a$ $(\rho_0 - \rho)$ vs. K_a in Figure 3, wherein the straight-line section AB represents the flow of the liquid through a fixed bed prior to fluidization, point B being the point of incipient fluidization. Region BC represents minor readjustments of the particles in the now fluidized bed to offer the largest possible free crosssectional area to flow with a resulting decrease in pressure drop until at point C, general fluidization is realized, and every particle is separated from its neighbor by a film of liquid and is in an agitated state. Further increases in velocity lead to a continually expanding bed, until, at the ultimate limit, the particles are so widely separated that they behave individually rather than as parts of a bed.

It was desirable to establish the dependence or independence of the fluidizing experiments upon entrance effect. Results plotted in Figure 1 are for experiments employing an equalizing section below the catalyst support, as pictured in Figure 8, such that there was a uniform velocity front into the test section, this being the ideal case for solid-liquid contacting. Limited experiments were performed, however, before employing the equalizing section, the liquid merely flowing from 8-mm. glass tubing into the test section, and the resulting high ratio of tubing velocity to the velocity in the test section and consequent initial liquid impetus produced excessive channeling of the liquid through the powdered 3.4 catalyst at the lower liquid velocities. This is illustrated graphically by the broken line on the plot of e vs. K, in Figure 3, and it ran be seen that fluidization does not occur at point B' as is the case for uniform velocity distribution, but that the bed rises only slightly until point C', which corresponds to point C on the pressure-drop correlation and, as previously explained, general fluidization is realized. From C' the curve shows a sharp rise to point E', above which it coincides with the curve for uniform entrance flow.

In all the 3A catalyst-liquid hydrocarbon fluidization experiments, a well-defined interface was observed between tine dense, fluidized bed and the clear liquid above it, characteristic of a "quiescent fluidized bed" as defined by Murphy (4), wherein there was little or no mixing of the solid particles, although the fluidized solids were in an agitated state and individually dispersed. This state is termed "particulate" fluidization and is to be expected for solid-liquid fluidization.

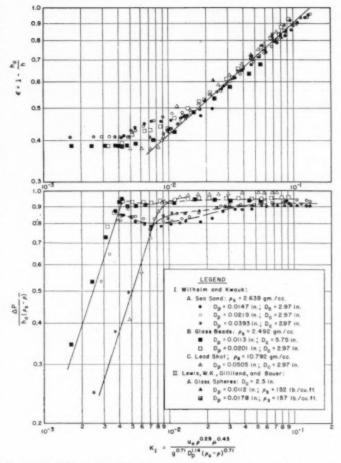


Fig. 4. Batch fluidization of uniformly sized spherical solids with water in intermediate-law region.

Intermediate and Newton's Law Regions

Reported by Previous Investigators. The application of Stokes' law to the 3.4 catalyst-liquid hydrocarbon batch fluidization systems suggests the applicability of free motion considerations to solid-liquid fluidization systems that are above the Stokes' law region. In the flow region where $K_{\mathcal{P}}$ varies between 2 and 500, which has been called the Intermediate law, the terminal velocity is defined by the equation

$$u_t = \frac{0.153 \ g^{0.71} D_p^{1.14} (\rho_t - \rho)^{0.71}}{e^{0.20_{+}0.40}}$$
 (6)

To account for the mutual interference in the motion of the many particles present in the liquid-solid fluidized system in this flow region, Equation (2a) is substituted into Equation (6) and results in the expression

$$\epsilon = k^{tt} \left[\frac{u_{\epsilon} \rho^{0.20} \mu^{0.40}}{g^{0.71} D_{\rho}^{1.14} (\rho_{\epsilon} - \rho)^{0.71}} \right]^{4}$$

$$= k^{t\epsilon} \left[K_{I} \right]^{4}$$

where k'' and d are constants. Equation (7) defines the fraction void-flow characteristics relationship for liquid-solid batch-fluidization systems in the Intermediate law region, wherein the terminal velocity of a particle in free motion corresponds to values of Re_p between 2 and 500.

In the region of turbulent flow resistance, i.e., where Re_p is a value between about 500 and 2×10^9 , the terminal velocity of spheres is defined by

$$m_t = 1.74 \left[\frac{gD_p(\rho_t - \rho)}{\rho} \right]^{1/2} \quad (8)$$

known as Newton's law. Here, as before, to represent a liquid-solid fluidization system, the mutual interference in the motion of the many particles in the bed must be taken into account. Substituting Equation (2a) in Equation (8) gives

$$\epsilon = \varepsilon \left[u_{\epsilon} \sqrt{\frac{\rho}{gD_{\theta}(\rho_{\epsilon} - \rho)}} \right]^{\epsilon}$$

$$= \varepsilon \left[K_{S} \right]^{\epsilon} \qquad (9)$$

where c and n are constants, which defines the relationship between fraction voids in the fluidized bed and the flow characterisstics for liquid-solid batch fluidization systems in the Newton's law region, wherein the free-falling velocity of a single particle corresponds to particle Reynolds numbers between about 500 and 200,000.

Since the batch-fluidization experiments did not include systems outside Stokes' law region of flow resistance, it has been necessary to use the experimental data reported in the literature by other investigators to test the relationships developed for the Intermediate law and Newton's law regions as expressed by Equations (7) and (9), respectively. In this connection, Figure 4 is a logarithmic plot of e vs. the calculated values of K1 for the solid-water batch fluidization experiments in the Intermediate law region reported by Lewis, et al., (3) and Wilhelm and Kwauk (6). In these experiments uniformly sized spherical particles ranging from 0.011- to 0.051-in. diam. were used, and the values of Re, at the free-settling velocities for these particles in water varied from 11 to 639. Figure 4 shows the logarithmic plot of e vs. K, to be a straight line, and this substantiates Equation (7 From the results plotted in Figure 4, the constants k'' and d of Equation (7) were evaluated by the method of averages, and the resulting equation of the curve in Fig-

$$\epsilon = 1.95 \left[\frac{u_{-\rho}^{0.73} \rho_{\mu}^{0.53}}{g^{0.73} D_{\mu}^{1.16} (\rho_{e} - \rho)^{0.73}} \right]^{0.367}$$
(7a)

In the region where the solids first begin to fluidize, especially with the smaller particles, the bed initially seems to expand by jumps. This inconsistent behavior is evidenced further by the pressure-drop correlations with the plot of $\Delta P/h_*(\rho_* - \rho)$ vs. K_L in Figure 4. However, above a value of ϵ equal to 0.5, a well-defined relationship is obtained between ϵ and K_L . It is evident that it is more critical to determine accurately the height of a fluidized bed at the higher values of ϵ and consequently the very high bed heights that might exceed the capacity of nominal-sized reactor sections.

Figure 5 is a logarithmic plot of e vs. the calculated values of K_B for the solid-water batch fluidization experiments in the Newton's law region reported by Wilhelm and Kwauk (6). In these experiments uniformly sized spherical particles ranging from 0.05- to 0.21-in. diam. and in density from 1.603 to 10.792 g./cc. were employed. Values of Re_B at the free-settling velocity of the particles in water ranged from 6.39 to 2180. It can be seen in Figure 5 that an excellent correlation is obtained between e and K_B . At the high values of K_B the curve shows a slight deviation from a straight line, but between K_B values of 0.12 to 1.0, a straight line is obtained on the logarithmic plot, as predicted from Equation (9). The equation of the curve between these limits is

$$e = 0.907 \left[u_a \sqrt{\frac{\rho}{gD_p(\rho_a - \rho)}} \right]^{0.400}$$
(9a)

Above a K_s value of 1.0 Figure 5 should be used for the greatest accuracy.

The pressure-drop data for these experiments are also correlated in Figure 5 in the form of the dimensionless group $\Delta P/h_e$ ($\rho_e - \rho$) plotted against K_E .

It is of interest to note that the results for the lead sphere-water system reported by Wilhelm and Kwauk (6) may be cor-

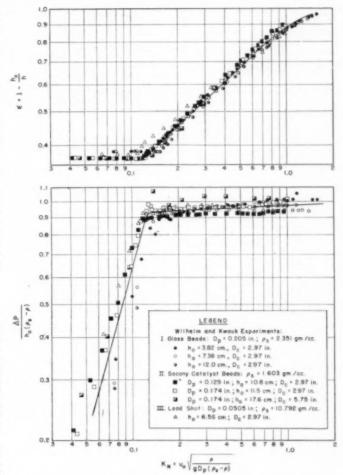


Fig. 5. Batch fluidization of uniformly sized spherical solids with water in Newton's law region.

related on either the $K_{\rm F}$ or $K_{\rm F}$ plot. The terminal velocity for one of these spheres in still water was determined experimentally to correspond to a $Re_{\rm F}$ value of 639, which is only slightly higher than the value of 500 expressed for the division between the intermediate and turbulent regions. This demonstrates a certain elasticity of boundaries from the $Re_{\rm F}$ values of 2 and 500 between the respective regions of flow resistance. Lapple, in his section in Perry's Handbook (5), shows another criterion to define the boundaries between the various regions of flow resistance that is expressed by the equation:

$$D_{ps} = K_s \left[\frac{\mu^2}{g\rho(\rho_s - \rho)} \right]^{1/3} \quad (10)$$

where D_{pe} is the critical particle diameter above which the law for free-falling particles will not apply. The value of K_{o} for Newton's law is 2360; Intermediate law, 43.5; and Stokes' law, 3.3. Use of Equation (10) was found to apply also to the solidliquid batch fluidization systems discussed heretofore; that is, for a given system D_{pr} may be calculated for the different regions using the respective values of K_c and compared to the actual particle diameter, and this comparison will define which free-settling law adaptation, as expressed by Equations (3), (7), and (9) and in Figures 1, 2, 4, and 5, respectively, is applicable to the system of the system of

Consideration of Particle Shape. It should be emphasized that the particles used in the experiments from which these correlations have been developed were spherical or nearly so, and, consequently, the correlations may be used with the greatest accuracy for particles whose shapes do not deviate far from the true sphere. Therefore, to present a correlation that accurately will apply to all particle shapes, consideration

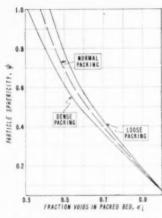


Fig. 6. Chart for estimating sphericity from fraction voids in packed bed.

0.9

Cushed Rock-Wales
System

Par 2 638 qm/sc.

Do 2 0.997 in.

Do 2.2.97 in.

W 0.4

Cushed Rock-Wales

Par 2 638 qm/sc.

Do 2.2.97 in.

W 0.2.23

O 4 Vs. K₁

From Figure 4.

4 or Wa Vs. K₁

From Figure 4.

6 or Wa Vs. K₁

From Figure 4.

7 or Wa Vs. K₁

From Figure 4.

8 or Wa Vs. K₁

From Figure 4.

9 or Wa Vs. K₁

From Figure 4.

9 or Wa Vs. K₁

From Figure 4.

10 or Wa Vs. K₁

Fr

Fig. 7. Application of particle sphericity as correction factor in fluidization of nonspherical solids.

must be given to a shape factor. Brownell, et al. (2), observed a relationship to exist between the fraction voids in packed beds of uniformly sized solids and the sphericity of the particles. Sphericity is defined as the ratio of surface area of a sphere having the same volume as the particle to surface area of the particle. This relationship is reproduced in Figure 6. For all the batch-fluidization experiments using uniformly sized solids (Figures 4 and 5) the fraction voids in the packed bed ranged from 0.368 to 0.408, and, as can be seen in Figure 6, if the curve for "loose packing" be assumed to represent the fluidized system, all these particles will have a sphericity of 1.0, which agrees with their observed shapes. In the case of the crushed rock-water system reported by Wilhelm and Kwank (6), the fraction void in the packed bed was 0.447, and the sphericity was 0.923 as predicted from Figure 6.

This system is in the intermediate region of flow resistance, and a plot of e vs. K1 deviates from the correlation of Figure 4 by a constant factor as seen in Figure 7, the actual values of e being higher than predicted from the curve. Since the resisting force offered by a fluid to a solid body in motion relative to the fluid is proportional to the area of contact, and this area for nonspherical particles is greater than would be calculated from the average diameter assuming a sphere, a given liquid velocity through a bed of fluidized solids will result in greater expansion to reach steady-state conditions for a bed of nonspherical particles than for spheres of the same volume with identical mass. Thus, the definition of sphericity suggests its use as a correction factor for nonspherical particles such that particle shape may be taken into consideration in the correlations. When e is multiplied by sphericity, \u03c4, for the crushed rockwater system and this product is plotted against K_I , the points fall on the curve from Figure 4. as may be seen in Figure 7, and this curve is also a plot of we vs. K, for the systems represented which, as previously mentioned, had a particle sphericity of 1.0. Tentatively, therefore, the use of particle sphericity supplies a method of correction to the correlations such that they will apply to nonspherical particles. For this purpose Figures 1, 2, 4, and 5 may be considered as plots of $\psi \epsilon$ on the ordinate vs. K_{I} , K_{I} , and K_{N} , respectively, to predict the fraction voids and the actual bed density in a solidliquid batch fluidization system from

the known flow characteristics of the system.

Experimental

Apparatus. Two 4-ft, glass columns with internal diam, of 3.7 and 6.5 cm., respectively, were used and either was fitted into the system as shown in Figure 8. The columns were fitted with two manometer taps for determining pressure drops. In either column a 6-in, equalizing section was allowed such that there was a uniform velocity front into the test section. Support for the solid particles consisted of a layer of glass wool held and wedged around the inner periphery of the column by a tight-fitting cork gasket made from a cork stopper bored in the center such as to leave a thickness of about 3/16 in. To prevent the gasket from slipping, it was supported by a brass tripod-ring stand set on the rubber stopper at the lower end of the column.

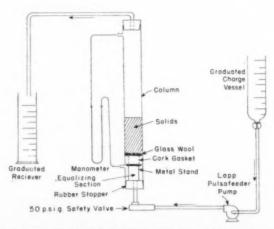


Fig. 8. Apparatus for 3A catalyst-liquid hydrocarbon batch fluidization experiments

Sieve Analysis, Mesh (U.S. Std.), wt. %;	Fresh 3A Catalyst	Used 3.4 Catalyst
Thru 325, (0.44)* On 325, (4474)* On 200, (74-105)* On 140, (105-149)* On 100, (149-177)* On 86, (177+)*	19.9 21.7 22.7 25.8 7.2 2.7	27,4 33,4 23,4 12,8 2,0 1,0
Weighted Avg. Particle Diameter, Micron Feet	86.0 2.82 × 10-4	68.8 2.26 × 10-4
Vol. % Voids (Packed Bed) Vol. % Pore Volume	43.1 30.3	34.1 11.7
Bulk Density, g. ec	0.578	1.132
Density of Solid, g. cc., at 90° F.:		
Saturated with nCs Saturated with iCa Saturated with gasoline	1.378	1.862
* Equivalent micron particle size.		

The pump used in the experiments was a small Lapp Pulsafeeder with a capacity of about 5 gal./hr. The liquid was pumped through a 50-lb./sq.in. gage safety valve to insure a constant flow rate for a given pump setting. Due to the low flow rates encountered, they were measured by means of graduated receivers. Pressure drops were measured with an air-water manometer.

Materials. A list of the physical char-acteristics of the 3.4 catalysts used in the experiments is given in Table 1. Average particle diameters were established graphical integration of the results of the sieve method of particle-size analysis by first plotting the data on logarithmic prob ability graph paper and then transposing the curve to rectangular coordinate paper.

In that these particles absorb liquids, the void measurements in the packed bed were somewhat complex. First, a known volume of catalyst measured at maximum consolidation was poured into a measured volume of liquid. The rise in liquid is equivalent to the actual volume of solid. The liquid was decanted and the particles dried in the atmosphere on filter paper until they were again in the fluid state; i.e., each particle was free from its neighbor and they could be poured freely. Assuming at this point that the liquid in the interstices had evaporated but that the strongly absorbed liquid in the pores of the catalyst remained, the rise in liquid when, as before, the catalyst was poured into the liquid is equivalent to the volume of the solid and its pores. Thus, by difference, the volume of voids in the packed bed is obtained. Triplicate deter-minations for each of three liquids were made, and a reproducibility of better than was achieved.

Bulk densities of the 3A catalysts at maximum consolidation were measured in a 500-cc, graduate. With this known, to-gether with the fraction of solid, pores, and voids for a packed bed of the particles and the density of the liquid, the density of the solid saturated with the liquid being tested was calculated.

The liquids employed in the fluidization experiments were n-heptane, i-octane, and a gasoline blend stock. For all but the latter liquid, the physical properties were taken from the literature. For the gasoline, the average of triplicate determinations of the kinematic viscosity was used, and its gravity was determined using an A.P.I. hydrometer

Procedure. The type of data taken during a run was relatively simple in nature. Beds of known volumes of the 3.4 catalysts were subjected to upflowing streams of the various liquids, and data were taken as to flow rate and extension of the beds after equilibrium had been attained. Whenever possible, pressure drops were measured across the column both in the fixed bed prior to fluidization and dur-ing the course f fluidization, and were corrected for the liquid head. Pressuredrop corrections for flow through the empty column were negligible for the relatively low flow rates employed.

Notation

 A_e = area of internal cross section of column

 $D_e = internal$ column diameter

 $D_p = \text{diameter of particle}$ g = acceleration due to gravity

h = height of bed at any instant h_i = height of packed bed

 h_n = height of hypothetical bed with zero interstitial voids

$$K_I = \frac{u_0 \rho^{0.29} \mu^{0.43}}{g^{0.71} D_p^{1.14} (\rho_s - \rho_s)^{0.71}},$$
dimensionless

$$K_X = u_a \left[\frac{\rho}{g D_p (\rho_a - \rho)} \right]^{l_2},$$

dimensionless

$$K_s = \frac{u_{\rm o}\mu}{gD_{\rm p}{}^2(\rho_{\rm o}-\rho)}\,, \ {\rm dimensionless} \label{eq:Ks}$$

 ΔP = pressure drop per unit area Ren = particle Reynolds number. $D_{\rho}u_{\rho}/\mu$, dimensionless

n = velocity of liquid past*the particle in the fluidized bed

 $u_n = \text{superficial velocity of liquid}$ based upon the empty column n, = terminal or free-settling velocity of particle

V = volume flow rate of liquid ϵ = fraction void space in solids

bed at any instant = $1 - h_a$ h, dimensionless

 ϵ_i = fraction void space in packed bed = $1 - h_o/h_i$, dimension $\mu = dynamic viscosity of liquid$

 ρ = density of liquid

 $\rho_s =$ density of solid saturated with liquid

6 = particle sphericity, ratio of surface area of a sphere having the same volume as the particle to surface area of particle, dimensionless

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Discussion

C. F. Gerald (Universal Oil Products Corp., Chicago, Ill.): I'd like to point out that the properties of the liquids flowing through the fluidized bed have not in this study, or any other in the literature, been varied widely. Work that I have done has indicated an anomalous effect of viscosity. Now I grant that these authors have done a better job than Wilhelm and Kwauk, who in the initial correlation reversed the effect of viscosity, but I think they might find part of the explanation for the difference in the slope of one of the curves shown here between their data fluidizing with hydrocarbon and Lewis, Gilliland and Bower's data fluidizing with water, if they examined the effects of the viscosity of the fluidizing liquid.

Also, I'd like to ask the authors if they don't think it would be somewhat easier to design and to use their correlations if instead of using three charts, one for Stokes' law, another for Newton's, and another for the intermediate region, they used a single chart based on only the drag coefficient, which will probably have to be calculated anyway; at least the Reynolds number must be checked in order to see the range in which one is working. As long as they have calculated the Reynolds number, they can go immediately to the standard drag coefficient chart, and, if their mechanism is correct, a single chart involving a relatively simple term-a lot of variables end up in the drag coefficient-might then make it a little easier. Would a single curve correlate all these data if the drag coefficient itself were used instead of the analytical expression of it?

E. W. Lewis (Humble Oil & Refining Co., Baytown, Texas): That question has been proposed before. In connection with calculating a drag coefficient from the Reynolds number, you realize that the Reynolds numbers we speak of for the individual particles were calculated only at the free-falling velocity to serve as criteria to determine which of the three correlations is applicable. We have seen attempts to correlate the three regions on one curve by using a reduced drag coefficient or friction factor on the abscissa vs. fraction voids. We have tried that for the systems that were similar in that they involved constant diameter spheres. A correlation of sorts was obtained, but the accuracy is not as good as that shown in our figures.

Relative to your comment concerning the effect of viscosity, the work we reported in our paper did cover a range of viscosities. Our experimental systems were in the Stokes' law region and although to tie down a correlation it is desirable to vary a given variable by manyfold we could not do this and still be in Stokes' law region. However, we varied viscosity through about a threefold change, and it showed no effect on the slope of our correlation. I believe we can be fairly certain that the difference in slopes between the curves for constant diameter and nonuniform-sized solids is due to particle-size distribution alone. It is apparent that with solids possessing a wide particle-size distribution the small particles will begin to fluidize at a liquid velocity lower than that for the average particle size. This is the reason for the lower slope in the case of the solids possessing the distribution of particle size.

L. P. Hatch (Brookhaven National Laboratory, Upton. N. Y.): How does your equation hold when you go to the limits, i.e., where the value of epsilon, representing the fraction of voids, is taken all the way to 0 or to 100%? It seems to me that your equation was based on an approach wherein the fraction voids were simply analyzed to a power, and that was determined from your experimental work. I'm wondering whether there is one thing lacking and that is the fraction of $(1 - \epsilon)$. I think you may need that other fraction if you want to go to the limits. Have you considered this?

E. W. Lewis: Yes, our equations hold all the way. Although our constants were determined experimentally, in all regions the curves extrapolated at 100% void, that is, at a value of $\epsilon=1$, to values which are in excellent agreement with the values of the abscissas for these dimensionless groups as calculated for free-falling bodies.

L. P. Hatch: Is this a Stokes' law region that you mean wherein particles interfere with each other? Isn't it some other relation which applies here rather than Stokes'?

E. W. Lewis: That may be. The reason we call it Stokes' law region is not to describe the phenomenon, but to indicate that the Reynolds numbers calculated at the terminal velocity of the particles that we used fall in the Stokes' law region. Simply, we used Reynolds number not as a measure of the fluidization properties but as a method of determining which of these three correlations is applicable to a system under consideration.

Nicholas Shoumatoff (West Virginia Pulp & Paper Co., New York, N. Y.): This paper, as I understand it, recommends that the weighted average particle size can be used interchangeably with the uniform size in determining Reynolds number and in the correlation for the different regions. Now when you have a varying particle size the small particles will be in a different Reynolds region from the large particles, particularly when you are in the nonlinear or turbulent-flow region. I doubt that the weighted average will properly account for that, and I also believe that that discrepancy accounts for some disagreement in the literature among the various investigators. Another point I'd like to mention is the matter of calculating particle diameter of irregular particles and then comparing that with the data on spheres. The point that Mr. Hatch made about the Stokes' law not applying in a dense bed of particles as compared with a single particle I believe is true and can be accounted for by using a binomial friction factor applying to the entire region.

E. W. Lewis: In connection with your first comment, we do not recommend that the weighted average particle size be used interchangeably with uniform particle diameter. We do recommend, however, that the equations for constant diameter spheres be used to calculate the performance of beds of particles with a wide particle-size distribution by applying the equation for the constant diameter spheres to each narrow range of particle size as determined by, for example, a sieve analysis, assuming the arithmetic mean particle diameter to be the average. The performance of the whole system is then calculated as the weighted average of the results for each fraction, and this method gave excellent agreement with the observed results of our catalysthydrocarbon systems.

As to calculating the Reynolds number from the weighted average particle diameter, it may in some cases throw you a bit off when looking at the boun-

daries for the use of these correlations. However, it checked for our solids.

With regard to your question concerning the calculation of the diameter of irregular particles, although the catalysts we used were not spheres, we calculated the diameter of these catalyst particles from the results of sieve analyses. Even though the particles were not spherical, their behavior could be predicted from the correlation for uniform-sized spherical particles. This may be an anomalous situation, but in our paper we show in one case the effect of sphericity of the particles. We used a sphericity term to correlate nonspherical particles and found that for this system-where crushed rock particles were fluidized-the use of the sphericity factor did correlate the results on our curve for spherical particles.

Nicholas Shoumatoff: I'd like to make just one more comment closely related to the one about the Reynolds number, and that is that in fluidization, particularly in the comparison of gases and liquid systems, for example, in Wilhelm and Kwauk's data (2), they got pretty good correlation with the liquid systems but not with the gaseous systems, which were relatively unstable, and they also pointed out that the particles were much more agitated in the gaseous systems and relatively steady in the liquid systems. That is rather significant because in fluidization, when speaking of the relative velocity between the particles and the fluid, you are usually taking the superficial velocity with respect to the bed as a whole. If that bed is being agitated, some of the particles actually have a much higher velocity relative to the fluid than others, and with the nonlinear resistance function when you simply take the average velocity of the bed as a whole, you will not correlate properly. I believe that accounts for the difficulties particularly with the gaseous systems. It may also apply to liquid systems highly agitated.

E. W. Lewis: I agree with what you have said, but I want to point out that all our systems involved liquids. We have not attempted to develop a correlation that will represent both liquid and gas systems on a single curve.

L. P. Hatch: I'd like to make one more comment with respect to what the previous speaker just mentioned—that in a fluidized bed of nonuniform-sized material it is possible to have a kind of turbulence in the bottom of the bed and a complete streamline effect in the top. In the extreme sense, it is like averaging the flow through a capillary tube and a 2-ft.-diameter pipe; they just don't average.

(Presented at A.I.Ch.E. Chicago Meeting.)

RADIOISOTOPES In Process Instrumentation

J. KOHL

Tracerlab, Inc.,† Berkeley, California

From August, 1946, to June, 1951, the United States Atomic Energy Commission made more than 18,000 shipments of radioisotopes. A number of these were used to solve process instrumentation problems. Radiations from beta-emitting radioisotopes have been used for measuring the concentration of ions such as lead, copper, or silver in solution and for determining the bulk density of granular solids. Neutron sources which utilize radioisotopes have been used for measuring the water content of solids. Radioactive tracers have been added to flowing systems to provide information on flow patterns in fractionation towers and retention time in settling basins. The recombination of ions formed by the interaction of radiation with gases provides a basis for a radiation anemometer suitable for measuring gas flow rates without placing a restriction in the gas duct. For some radioisotope applications this presentation includes type, quantity and properties of the radioisotope; approximate cost; instrumentation requirements; and typical results.

THE recent availability of radioisotopes from the A.E.C. reactors has resulted in a number of applications which are discussed in this paper; however, radioisotope applications in the field of process instrumentation started as early as 1913. In that year, Hevesy and Paneth (13), working in Germany, determined the amount of water flowing in a river and measured the rate of self-diffusion of lead. They performed their experiments using naturally occurring radioisotopes associated with the radioactive disintegration series of uranium

and thorium, since at that time no artificially produced radioisotopes were available.

From 1913 to 1946 a few additional applications were carried out using naturally occurring and cyclotron-produced radioisotopes. This work included experiments on the measurement of thickness, specific gravity and liquid level using radium and determination of wear using cyclotron-produced P-32, In August, 1946, the U. S. Atomic Energy Commission (15) started distributing radioisotopes produced in its Oak Ridge nuclear reactor. A 2,000 kw. reactor at Oak Ridge which had been designed to produce small amounts of plutonium for chemical experimental work was converted to the production of radioisotopes. Figure 1 is a schematic drawing of this reactor. It is 47 ft. long, 35 ft. high, 38 ft. wide, with concrete walls 7 ft. thick. At present more than 1,000 departments or laboratories in more than 500 institutions in the U.S. are using radioisotopes from Oak Ridge. However, the United States is no longer the sole possessor of reactors that produce radioisotopes: Canada. Great Britain, Norway, and France are all now operating reactors.

Before one can intelligently appraise recent radioisotope applications and decide whether a problem can be solved by the use of radioisotopes, definitions of important terms and a discussion of



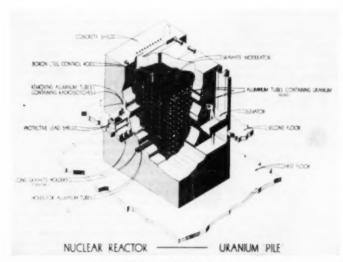


Fig. 1. Schematic drawing, Oak Ridge reactor.

the properties and availability of radioisotopes are needed.

Isotope. Atomic species of the same atomic number that belongs to the same element but has different mass numbers. Radioisotopes are useful as sources of radiation and as "tracers." Their tracer use arises because of their exhibit of substantially the same chemical behavior as the stable species of isotopes while emitting radiation which permits determining their identity and bention.

identity and location.

Table 1 lists the principal types of radiation emitted by radioisotopes. The radioisotopes available from the A.E.C. are produced in nuclear reactors by two methods. Fission of fissionable materials, such as uranium-235 or plutonium, results in a large number of elements ranging from element 30 to element faranging from element cerium, barium, strontium, cultumbium, cerium, barium, strontium, cultumbium, cerium, barium, strontium, ruthenium, and cesium. Substances can be placed in a reactor and activated by bombardment with neutrons. This technique is used to produce

radioisotopes and to activate special objects

such as piston rings, or distributor points

for wear studies.

Millicurie. In radioactive work the units curie and millicurie are commonly used. A curie corresponds to 2.2×10^{10} dissintegrating atoms per minute (dpm) and a millicurie is 2.2×10^{9} dpm. Since one can measure 100 dpm of a beta emitter such as P-32 with a Geiger-Mueller counter, one has available a dilution factor of 2.2×10^{7} for 1 mc.

Procurement of Radioisotopes. The radioisotopes produced in the nuclear reacters of the U. S. and other countries are available only to qualified users. To qualify for radioisotopes the A.E.C. requires suitable counting and monitoring equipment as well as remote handling equipment, lead bricks, shielded storage cabinets, etc. Equipment suitable for a modest radioisotope laboratory represents an investment of approximately \$2,500.

A.E.C. also requires training and experi-

A.E.C. also requires training and experience in haudling radioisotopes by a recipient of radioactive materials. This training can be secured at the Oak Ridge Institute of Nuclear Studies (four weeks' training course) or by an intensive course at one of the commercial radiochemical laboratories.* Once a laboratory has obtained trained personnel, the necessary equipment, and the radioisotopes, it can carry out radioisotope applications or experiments.

Radioisotope Applications

Fractionating Tower Flow Pattern. The California Research Corp. has carried out a flow-pattern study in a threesectional feed preparation unit. In this study, reflux flow patterns were observed in a 55,000 bbl./day vacuum tower with a 12-ft, diam, bottom section containing five trays, 27-ft. diam. center section with eight trays, and a 151/2-ft, top section with seven travs. It was decided to investigate flow patterns in the tower without a shutdown of the unit by using radioactive tracers. Approximately 3 millicuries of an oil-soluble antimony compound were injected into the top reflux line to the tower. Geiger counters outside of the tower were then used to follow the flow of the tagged reflux. In this tower the tray flow is alternately from the center to the outside and then from the outside to the center with a large number of downcomers. By moving about the tower it was possible to find the listribution of the radioactive material in the various downcomers. which established the nonuniformity of flow across the trays. The flow of the radioactive compound was followed over several cycles. Each time it was a little more diffused as it flowed over the travs and down the downcomers. Measurement of the circulation time permitted calculations of the total holdup in the system. The radioactive antimony-124 used in this experiment has a 60-day half-life and a cost of \$33 for 11 millicuries. The 11 millicuries represents under 2/10 g. of pure antimony metal.

Large Flow Measurement. Radioactive Na-24 has been used in determining that 33,000 gal./min. of water flowed through a condenser at the Westport station of the Consolidated Gas, Electric Light & Power Company of Baltimore by means of a dilution technique (17).

Use of radioactive materials for flow tests has advantages over the use of dyes or salts, since identification is easily, quickly, and accurately accomplished even through the walls of the pipe. Weight concentrations required for identification are much smaller than those required of dye or salt, and the data obtained are not affected by variations in salt originally present as in the case of sewage or salt water cooling.

Flow Patterns in Ventilation Systems. The British carried out experiments in an asbestos factory in which it was suspected that despite great care to provide adequate ventilation, asbestos dust produced in one part of the factory was making its way to other sections against the general direction of the ventilating air stream. To confirm the origin of this dust a radioactive vapor Br-82, 36 hr., .465 m.e.v. B, 0.55 to 1.31 m.e.v. y, \$12/70 mc.) was liberated at the carding machines where the asbestos dust was produced. Samples of air were then taken at various places in the factory. The radioactive vapor was absorbed out of this air and measured with a counter. From the information obtained by this technique, it was possible to modify the ventilating system to prevent unwanted asbestos dust from penetrating to the remainder of the

The Laboratory of Physical Biology of the National Institute of Health at Bethesda, Md., carried out experiments using radioactive potassium-42 (K-42, 12.4 hr., 3.58 and 2.04 m.e.v. β-, 1.51 m.e.v. y \$12/125 mc.) to test the efficiency of various isolation devices in the ventilating system of a building designed for research in bacteriology. The radioactive material was put in solution and injected into the air at appropriate places by means of a bubbler system, which was known to deliver macroscopic droplets. Geiger-Mueller counters connected to scaling circuits installed at various places in the ventilating ducts provided a measure of the number of droplets carried to each Geiger-Mueller

Interface Location. In oil product pipe lines a number of different products are frequently handled in one line. In order to minimize loss of different products at the terminus, Standard Oil Company of California has inaugurated a system of injecting an oil-soluble tagged compound of Sb-124 into the product line at the time a change in product is

made (14). The pumping stations along the route have detectors which pick up the coming of the interface and forewarn the operators so that they may properly handle the new product when it arrives at their particular station.

TABLE 1.- PRINCIPAL TYPES OF RADIATION EMITTED BY RADIOISOTOPES

Type	Symbol	Description	Rest Mass (0 = 16)	Charge (Electron = 1)	Range in Air	Ion Pairs /cm. in air
Alpha particles	a	Nuclei of helium atoms	4	+2	2 to 9 cm, for 3 to 10 m.e.v.	30,000 to 70,000 (varies with distance from source)
Heta particles	Β	Electrons circled from a nucleus	$\frac{1}{1840}$	-1	160 to 2,000 cm. for .5 to 5 m.e.v.	150 to 40 for 0.1 to 5.0 m.e.v.
Gamma Pays	γ	Electro- magnetic radiations produced only in nuclear processes	None	Nane	15,000 cm. 3½ value thickness for 1.5 m.e.v.	1/100 of number of pairs produced by same energy \$\beta\$

^{*}For sealed sources, such as are used in beta gages, semiannual radiation surveys by the supplier can serve in place of the training and instrumentation.

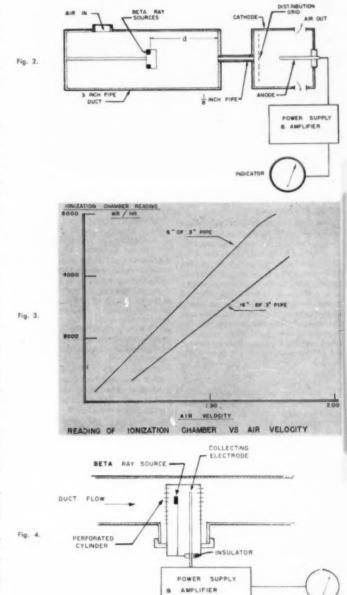
In a second application of interface location, an oil-well-acidizing company is using a radioactive material in solution in its acid. By dropping a Geiger-Mueller tube into the well casing they are able to locate the acid-oil or acid-drilling mud intertace. Since the acid is pumped down the center pipe and rises in the annulus around this pipe, attainment of a maximum counting rate indicates that the acid has passed the counter and risen around it in the annulus. By this technique the acid may be held at the desired level, to attack the oil-bearing strata.

Small Flow Studies - Ionization Anemometer. Another potential application is the use of radioactive materials to measure low flow rates while providing no restriction to the flow. It is expected that this technique will find application in detecting leaking relief valves. The ionization anemometer makes use of the fact that ions formed in a gas stream are subject to recombination. The degree of recombination depends on the number of ions and on the time after formation. The British report using this phenomenon to measure wind velocity. As a first step in the development of a commercial ionization anemometer, the test setup shown in Figure 2 was constructed and operated. Figure 3 illustrates the data obtained with the experimental setup. An instrument now in construction is illustrated in Figure 4.

Furnace Flow. The British Iron and Steel Research Association has used radon to determine gas transit time in a driving iron blast furnace. Eight millicuries of radon were injected into the air stream by means of explosives in order to give sharp pulses of the radioactive material. Samples of the radioactive gas were then taken every second at the top of the burden. By finding the amount of radioactivity in each sample, it was possible to estimate the mixing and flow velocity in the blast furnace (2).

Wind Tunnel Flow. In another British experiment, radon was used for studying the air distribution in a wind tunnel (4).

Diffusion Measurement. Radioisotopes are used for measuring extremely slow velocities such as are obtained in diffusion in metals, porous bodies, liquids or gases (20, 10). Self-diffusion rates of cobalt in cobalt, or silver in silver, can be determined by radioisotopes while such measurements cannot be obtained by any other technique. In one diffusion study of metal through metal, radioactive cobalt was plated on a cobalt bar which was then heated for the desired time and the surface counted



IONIZATION ANEMOMETER
PROPOSED INSTRUMENT

INDICATOR

for determination of depth of diffusion as a function of time and temperature.

Mixing-Degrees of Uniformity. It is possible to use radioisotopes to determine the uniformity of mixing of liquids or dry solids. Solids consisting of powdered salts, vitamins, oats, and other materials are all mixed in large blenders for animal feeds. The question arises as to the uniformity of the different constituents in the feed. The British have carried out experiments in which they used radioactive sodium-24 in sodium chloride as the tagged compound and determined the quantity present in samples taken from the mixer at different times (3). The amount of Na-24 in samples taken from two tons of poultry mix or broiler feed can be determined if approximately 1 millicurie (2.2 × 109 dpm) of Na-24 as sodium chloride is added to two tons of feed. The isotope cost for an experiment of this type is under \$10. (2 tons = 2×10^6 g, or 10^3 dpm/g. at even mix.)

In a Canadian experiment, pulp fibers were tagged with radioactive iodine-131. (I-131, 8.0 days, half-life, 0.32 and 0.60 m.e.v. \(\beta^-\), \(\gamma\) from 0.08-0.64 m.e.v., 75¢/ mc.) The fibers so tagged were blended with the stock in one of a battery of bix Bird screens on a newsprint machine (23). Rolls of paper were wrapped around Geiger-Mueller tubes to determine the relative quantity of I-131 and thus to determine quantitatively the distribution of the tagged fibers in the finished newsprint paper. Results permitted an evaluation of the blending of the stock in the zone of the paper machine between the Bird screens and the point at which the formation became fixed, The technique also permitted measurements of the uniformity of distribution of the radioactive fibers in the paper. In the experiment, 100 mc. of I-131 were used to tag 31/2 tons, or more than 600,000 sq.1t. of finished paper. (8 × 10-7 g. of I-131.)

In experiments at Harvard, the quality of mixing and degrees of short-circuiting in model sewage-settling tanks have been determined, using radioactive 1-131. Field tests were also made to determine retention tin 2s in a 60 ft. × 35 ft. primary sedimentation tank in a 100-ft. diam. circular clarifier and in a 4.9 acre pond. For the pond test 5 ml. (20 mc.) of 1-131 tracer were used. The iodine was precipitated as silver iodide for counting. A similar test with salt as tracer would require 1,000 lb. of salt (5).

Wear Measurement. The British have reported using small pellets of cobalt-60 which are built into the lining of blast furnaces (21). These furnaces are lined with 2 to 3 ft. of fire brick or carbon and normally run for six or

seven years before relining. Pellets as released due to wear can be detected in the iron or their absence noted using a portable counter.

In a number of experiments, gears, bearings, piston rings, and distributor points have been irradiated in the reactors of the U. S. Atomic Energy Commission to produce radioisotopes directly in the irradiated material. (The quantity of radioactivity produced by irradiation depends on the neutron flux, the time of irradiation, quantity of target material and its neutron absorption cross section.) The U.S. A.E.C. charges \$12/week, or \$33/month for irradiation. For details see (25). The radioactive gear, or piston ring, is placed in test engines which have been operated with varying cylinder temperature, type of lubricant, and quantity of sulfur in the gasoline (22). The amount of material worn from the ring is determined by counting the radioactive metal in the lubricating oil. This technique permits determining quantities of iron worn from a surface as small as a fraction of one milligram. This technique has the further advantage of providing a continuous method for measuring wear without requiring dismantling the engine and weighing the parts.

A tungsten carbide wire-drawing die has been irradiated and its wear measured by counting the activity on the formed wire (21). Autoradiographs * of the wire provided information on the distribution of the die wear debris and on the amount of wear for various die lubricants.

Phosphorus-32 has been added to rubber which has been compounded into tires in a technique for measuring tire rate of wear. These tests permitted continuous measurement of wear as a function of tire air pressure, temperature, revolutions per minute of wheel, and power application without having to wait for fleet tests of large numbers of tires. As used, the technique involved measuring the amount of radioactive rubber left on the road behind the tire, using a Geiger counter which rode behind the car and measuring the amount of radioactive rubber blown into the air from the tire-road interface.

Radioactive compounds have been added to floor waxes which have been applied to typical surfaces and their removal studied by measuring the amount of radioactivity remaining and that transferred to the device that has been moved over the floor. In a similar study radioactive materials were added to car protective finishes. The protected painted surfaces were then subjected to

water and detergents at various temperatures, and the amount of wax remaining was determined by counting the painted surface after each test.

Area Measurement. The areas of small irregular sheets of material, thick enough to stop all alpha particles from a given source, can be measured by placing the sheet over a uniform flat source of the alpha radiation and measuring the change in ionization resulting from the absorption of the radiation by the sheet. The ionization is measured in a chamber the same size as the flat source over which it is placed. In one application, polonium (Po-210, 140 days, 5.3 m.e.v. a, no β, weak γ, \$5/mc. from radium companies) was used as a source of radiation, since its alpha rays are completely absorbed by very thin sections of material (7). (The alpha rays from Po are absorbed by approximately .025 mm. or one thousandth of an inch of aluminum.)

Viscosity Determination. The French have developed a falling-ball viscosimeter for use with nontransparent, highly viscous liquids (11). With this instrument, viscosity is determined by measuring the time taken for a radioactive ball to travel a fixed distance through the liquid. A clock operated by a Geiger counter is started when the ball passes one slit in a lead block and is stopped when the ball passes a second slit.

Position and Displacement Measuring Devices. A small quantity of a gamma-emitting radioisotope, such as cobalt-60, has been placed in pipe-line scrapers or "go-devils" to permit its location when stuck in a pipe-line (24). Table 2 presents the quantity of radioactive material needed vs. the distance below the surface for detection of such scrapers. As now used, the technique requires a radioactive source which is mounted in or on the scraper. A portable Geiger-Mueller-type detector carried by the line-walker reveals the location of the scraper by its response to the radioactivity.

A small amount of radioactive material has been placed on the wrist of a

TABLE 2,—SOURCE STRENGTH RE-QUIRED FOR DETECTION AT VAR-10US COVER DISTANCES (24)

Source Strength Mc of Co - 60

	00 00			
Distance	Soil Half	Soil Half		
Below Surface	Thickness 4.4	Thickness 6.0		
in.	in.	in.		
40	31.25	31,25		
50	265.6	156,25		
60	1875.0	937,5		
70	12,500.0	3750.0		

Autoradiography is a technique by which radioactive material is located by permitting it to expose photographic film.
 For details see (27).

punch-press operator so that the presence of his hands near the press operates a Geiger counter which prevents operation of the press.

Tachometers. A patent has been granted for a device whereby a mechanical register-is actuated as radioactive material, mounted at a point on the circumference of a rotating wheel, passes near a detecting device (1). It has been suggested that this tachometer be used for the testing and calibration of electric whr. meters.

Permeability. In an interesting use of the radioisotope tritium (H-3, 12.5 years, 0.0189 m.e.v. β, 10¢/mc.), a British industry is using tritiated water to study the permeability of thin, flexible plastic sheets (21). They clamp a septum of the wrapping over a dish of tritiated water solidified by gelatin. Methane is passed over the upper surface of the septum and then is pumped into an all-metal counter. The counter pulses resulting from the diffused tritium are then fed to an amplifier and into a scaler. The time required to obtain a steady reading is only three minutes in the case of thin thermoplastic materials and ten minutes with hygroscopic films. Previously used gravimetric methods took at least 24 hr.

Thickness and Coverage Measurement. The absorption of radiation by matter is a phenomenon that permits measurement of the mass of material between a source and a receiver. For thin materials (under 5 mg./sq.cm.-0.0009 in. A1) the absorption of alpha radiation can be used to provide a measure of weight per unit area. In the range 1/2 mg./sq.cm. to 1,000 mg./sq.cm. -0.00004 in. to 0.16 in. of A1, beta radiation, such as is emitted by strontium-90 (Sr-90, 25 years, .54 m.e.v. B-, No y. \$36/mc.) - (Daughter Y-90, 61 hr., 2.18 m.e.v. β^-), carbon-14, and many other radioisotopes, is used for measuring weight per unit area. The beta absorption gages (9), such as is shown in Figure 6 use a 10-mc. \$\beta\$ source which is placed beneath the paper, rubber, plastic or metal sheet. An ionization chamber above the sheet provides a measure of the radiation that penetrates the material.

Scattering. Radiation passing near a nucleus or one of its planetary electrons is changed in direction by an interaction between its charge or field and that of the nucleus or electron. Radiation that has been changed in direction is termed scattered radiation. Radiation that has been scattered in the backward direction is termed backscattered radiation. In the case of beta radiation, amount of scattering is a function of the thickness of the scattering medium, the energy of

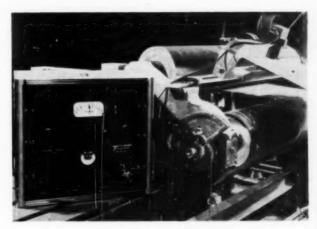


Fig. 5. Beta thickness gage installation.

the beta rays, the number of nuclei per unit volume and the charges on the nuclei in the scattering medium.

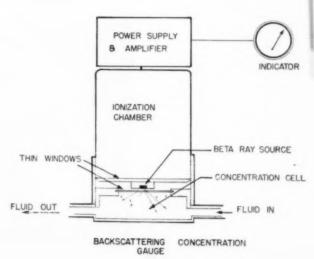
Beta Backscattering Gages. In one application backscattering is used to measure thickness of coatings and films on rolls, such as rubber sheet on steel rolls, tin plate on a steel base, and lacquer on a tin base.

Chemical Composition. Using Beta or Gamma Backscattering. Since beta-backscattering is sensitive to the atomic number of the back-scattering material, high atomic number inventions in a low atomic number medium can be detected by a backscattering technique.

For example, it is possible to detect lead, silver, copper, nickel, or vanadium in water or in a solid, such as paraflin (19). For the measuring device, a modified beta backscattering gage, such as is shown in Figure 6, is satisfactory. A Sr-90 source can be used for the beta rays. Figures 7 and 8 indicate the type of measurement obtainable by this technique. Since gamma-ray-scattering is also a function of the atomic number of the scattering medium, gamma rays may be used for obtaining compositions.

Using Neutrons. Fast neutrons, such as are obtained from a radium-beryllium or antimony-beryllium source are slowed down by collision with hydrogen atoms.

Fig. 6.



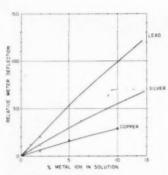


Fig. 7. Relative meter deflection vs. per cent of metal ion in solution-construction gage.

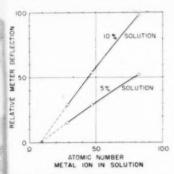


Fig. 8. Relative meter deflection vs. atomic number metal ion in solution-construction gage.

These slowed-down neutrons may be detected by activation methods. Since the number of fast neutrons slowed down to n velocity such that they can be captured and counted is a function of the hydrogen atom concentration of the scattering media, the technique can be used for measurement of hydrogen concentrations (8).

The neutron-capture cross sections of various elements differ by measurable amounts. Slow neutrons (such as can be obtained from a radium-beryllium source in a water or paraffin-filled container) are captured preferentially by atoms with a high slow neutron-capture cross section; thus, an unknown sample can be subjected to irradiation by slow neutrons and the irradiated material counted for induced radioactivity. A measure of this activity, of its half-life and energy permits identification of the radioisotopes that were formed by the neutron bombardment. From this knowledge, the original composition can be deduced (26).

At energies intermediate between fast neutrons and thermal neutrons resonance absorption takes place. This is characteristic of certain elements for

given resonance energies and provides a sensitive detection scheme for those particular materials. It has been suggested that neutron activation be used for ore sorting.

Soil Moisture Measurement, Neutrons have been used to provide a measure of soil water content (6). Neutrons from a radium-beryllium source are slowed down by water in the soil and detected by a rhodium foil which has a high slow neutron-activation cross section. A Geiger-Mueller count of the rhodium foil provides an indication of the number of neutrons that were slowed down and thus of the water content of the soil surrounding the equipment.

Oil-well-core Water Content. The water content of oil-well cores has been measured using the neutron slowingdown technique and by adding a radioisotope to water, pumping this water through a core and then measuring the amount of activity at different points in the core by a scanning Geiger-Mueller tube (16).

Density and Specific Gravity-Bulk Density of Granular Solids. Since abscrption of beta or gamma radiation is a function of the mass of the material between the source and detector, if a material of fixed thickness and unknown density is placed between source and detector, the response of the detector will be a function of this density. Figure 9 illustrates this type of equipment. The system can be used, for example, on powdered soaps, dry cereals, synthetic detergents or any granular material. It can be used also on liquids or solids (18, 12).

In a gamma-ray density application, the density of undisturbed soil has been

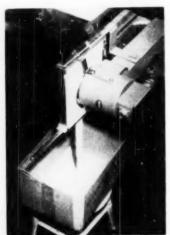


Fig. 9. Bulk density gage-laboratory set up.

measured using a 4-mc. radium source and a Geiger-Mueller tube (6). In this technique scattered gamma rays rather than absorbed ones are used as the variable permitting detection of the soil density.

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INDUSTRIAL VIEWPOINTS ON SEPARATION PROCESSES

PART III

This is the third and final section. Parts I and II appeared in the October and November issues.

KARL H. HACHMUTH Phillips Petroleum Company, Bartlesville, Oklahoma

THE methyl ethyl ketone-n heptane-toluene system was chosen to illustrate the method of calculating an azeotropic distillation because phase-equilibrium data are available (35). It is not as suitable a system as desired because the hydrocarbons can be separated by ordinary fractional distillation. However, for illustrating the method it is satisfactory.

To simplify the following description certain assumptions are made:

- 1. The feed consists of n-heptane and toluene only. In actual practice sev-eral more hydrocarbons would be present.
- The quantity of liquid leaving each bubble tray per unit time between points of heating or cooling or of material entering or leaving the column is the same (on a molal basis). In practice, the molal overflow may vary considerably from tray to tray in cer-tain parts of the tower. Heat-balance calculations will reveal such variations and will permit estimation of true V/L ratios rather than the approxi-mate ones obtained when constant molal overflow is assumed.
- 3. Calculations are made as if perfect equilibrium were attained at each contacting step. This is sometimes the case for binary mixtures. When multicomponent mixtures are handled, some of the components will more nearly approach equilibrium than others
- 4. Constant pressure throughout the fractionator.

The purpose of the solvent used in azeotropic distillations is to change the relative volatilities of the compounds being separated. To do this the solvent must be present in an appreciable concentration, at least as much as 30 per cent and preferably more than 50 per cent. The following calculations show that the solvent tends to approach the concentration where its equilibrium vaporization ratio is unity. If this occurs at an unfavorable solvent concentration, the performance of the azeotropic tower will be unsatisfactory.

The phase-equilibrium data for the methyl ethyl ketone-n-heptane toluene system shows that the methyl ethyl ketone K = 1.00 at a solvent concentration of 0.76 when the concentration (on a solvent-free basis) of n-heptane is 1.00. By approaching this limiting concentration in the top end of the tower, lower but effective concentrations of solvent may be maintained throughout the tower where the separation between n-heptane and toluene is taking place. Hence, methyl ethyl ketone is a suitable solvent as far as its volatility relationships in the azeotropic tower are concerned.

The first step in solving a problem in azeotropic distillation is to determine the approximate concentration of the solvent throughout the tower. When this is known, the relative volatilities of the key components being separated may be estimated and the number of required equilibrium steps estimated. The for-

$$\Delta_{xi} = x_{i,n} \left(\frac{K_{i,n} V_n}{L_{n+1}} - 1 \right) - \frac{\Delta_i}{L_{n+1}}$$
(6)

will give the change of concentration of the solvent (considering it the i component) in the liquid phase when proceeding upwardly in the tower from the n to the (n + 1) equilibrium step. Units used in this equation must be consistent, in this case mole fractions and moles per unit time.

The solvent concentration in the tower will tend to approach values where $\Delta_x = 0$. Setting $\Delta_x = 0$, using the relation $V_n - L_{n+1} = \Delta_{\Sigma i,j,k}$. . .

$$L_{n+1} = \frac{\Delta_i - x_{i,n} K_{i,n} \Delta_{\Sigma_i,j,k} \dots}{x_{i,n} (K_{i,n} - 1)}$$
(7)

The solvent can be added to the tower at the top, at the feed entry or below the feed entry or at some combination of these entries. To study the effect of these entries on the solvent distribution within the tower, assume a feed consisting of 85 moles of n-heptane and 15 moles of toluene/unit time and a distillate product containing about 0.004 mole fraction toluene and a bottom product containing about 0.005 mole fraction heptane (all on a solvent-free basis). The distillate product will be 84.93 moles of heptane plus 0.37 mole of toluene/unit time and the bottoms product will be 0.07 mole of heptane and 14.63 moles of toluene/unit time. As pointed out before, the solvent concentration tends to approach 0.76 mole fraction at the top of the column. Hence the distillate product per unit time must

$$\frac{84.93 + 0.37}{0.24} ,76 = 270$$

moles of solvent before solvent separa-

If the assumption is made that the tower is so operated that no solvent remains in the bottom product then:

if all the solvent is added at the top of the tower

$$\begin{array}{lll} \Delta_1 & = 0 \\ \Delta_{\Sigma 4,J,h} & \ldots & = 85.3 \end{array} \left. \begin{array}{ll} \text{above feed entry} \\ \Delta_4 & = 0 \\ \Delta_{\Sigma 4,J,h} & \ldots & = -14.7 \end{array} \right\} \text{below feed entry}$$

$$\Delta_i = 0$$
 $\Delta_{\Sigma i,j,h} \dots = -14.7$ below feed entry

if all the solvent is added at the feed

$$\Delta_1 = 270_+$$

 $\Delta_{\Xi i,j,k} = 355.3$ above feed entry

$$\Delta_i = 0$$
 $\Delta_{\Sigma_i,i,k} = 0$
 $\Delta_{\Sigma_i,i,k} = 0$
below feed entry

if all the solvent is added below the feed entry

$$\Delta_i$$
 = 270
 $\Delta_{\Sigma 4, j, k}$. . . = 355.5 above feed entry

$$\Delta_i$$
 = 270 below feed entry $\Delta_{\Sigma i,j,k}$: \approx 255.3 but above solvent entry

$$\Delta_i = 0$$
 below solvent $\Delta_{\Sigma i,j,k} \dots = -14.7$ entry

For the case of all the solvent added at the top of the tower (dropping unnecessary subscripts), from Equation

$$L = \frac{-xK85.3}{x(K-1)}$$

for above the feed entry. It is evident that K must be less than unity to obtain a reasonable answer. K reaches its lowest value (0.95) for an x of about 0.89. At this condition

$$L = \frac{.95 \times 85.3}{.05} = 1620 \text{ moles/unit time}$$

This is the lowest L which will give a relatively constant concentration of solvent over several equilibrium steps at the top of the tower. If a smaller L is used Equation (6) shows that Δ_r will be positive (x decreasing down the column) and that the rate of decrease in x will accelerate as x becomes smaller (because K increases with decrease in x for all values of x less than 0.89).

When the solvent is added at or below the feed entry Equation (7) gives

$$L = \frac{270 - xK \ 355.3}{x(K-1)}$$

for above the feed entry. When x = 0.76 and K = 1.00 any value of L will satisfy this equation, hence the limiting conditions must be at some other point than the top of the tower. Applying Equation (7) just above the feed entry where the ratio of heptane to toluene is assumed to be the same as in the feed, that is 85/15, a series of values for L for various solvent concentrations is shown in Table 1. This table also shows the corresponding solvent-free (K) and (L)/(K)(V) values for toluene just above the feed and at the top of the tower. The function of the tower above the feed entry is to act as an absorber for toluene. Hence the larger the (L)/(K)(V) values for toluene the more effective the tower will be in its desired function. The (L)/(K)(V)value just above the feed reaches a maximum at about 0.5 concentration of the solvent. Simultaneously the (L)(K)(I') at the top of the tower is about the same as just above the feed. (According to the simplifying assumptions, L at the top of the tower is assumed the same as L just above the feed.) Using greater concentrations of solvent just above the feed will require a somewhat smaller L (smaller reflux) but at the expense of a more difficult separation. Without extensive calculations to determine the true optimum, a solvent concentration of 0.5 just above the feed looks to be a good value to use. The next step is to see how this value will fit the requirements below the feed entry.

It all the solvent is added at the feed entry and if x_t and $x_H/(x_H+x_T)$ are the same just below the feed entry as just above, Equation (7) reduces to

$$L = \frac{1.26 \times 14.7}{1.26 - 1} = 71.2$$

This doesn't look like a satisfactory value for L but trying it in the solventfree stripping factor for heptane gives

ove, Equation (7) reduces to
$$I = \frac{1.26 \times 14.7}{1.2} = 71.2$$

$$\frac{(K)(V)}{(L)_H} = \frac{1.08(71.2 - 14.7)(1 - 0.5 \times 1.26)}{0.5 \times 71.2} = 0.634$$

Since (K)(V)/(L) for heptane is less than unity the heptane will not be stripped from the toluene below the feed entry when an L as small as 71.2 is used.

If all the solvent is added somewhere below the feed entry and if x_a and x_H $(x_H + x_T)$ are the same just below the feed entry as just above, Equation (7) reduces to

$$L = \frac{270 - 0.5 \times 1.26 \times 255.3}{0.5(1.26 - 1)} = 839$$

$$\frac{(K)(V)}{(L)_H} = 1.042$$

According to the above results the tower is operable but the value of 839 for L means that some condensation would be necessary at the feed entry because L above the feed entry plus the feed only equals 355 + 100 = 455. For lower investment and operating cost it would be desirable to avoid use of a condenser at the top of the bottom section of the tower. Some division of the solvent between the feed entry and a point lower in the column will eliminate the necessity of this condenser. Let Sp equal the solvent entering with the feed. (Assume the feed and solvent are at such a temperature that their effect is to increase the liquid downflow in the tower just exactly equal to the quantity of solvent and feed added.) Then for Equation

TABLE 1.—CHANGE IN
$$L$$
 AND ABSORPTION FACTORS WITH SOLVENT CONCENTRATION

	$\frac{x_H}{x_H + x_T} = 0.85, x_{(salsens)} \text{ as ab}$		shown	$\frac{x_H}{x_H + x_F} = 1.00, x_{(solvent)}$		
Solvent Concentration	Solvent K	$\lambda_{\rho}^{L} = 0$	Toluene (K)	Toluene (L) $(K)(V)$	Toluene (K)	Toluene (L) (K)(V)
0.1 0.2 0.3 0.4 0.5 0.6 0.7	3.26 2.30 1.74 1.44 1.26 1.14 1.045	692 410 381 371 355 321 331	0.79 0.72 0.66 0.59 0.55 0.505 0.46	1.111 1.102 1.148 1.225 1.228 1.190 1.155	0.413 0.413 0.413 0.413 0.413 0.413	1.501 1.297 1.254 1.236 1.210 1.150 1.160

$$L = 355 + 100 + S_F$$

 $\Delta_i = 270 - S_F$
 $\Delta_{\Sigma_{i,j,k}} \cdot \cdot \cdot = 255.3 - S_F$

Substituting these values in Equation (7) and solving gives $S_F = 100$ and L = 555. $(K)(V)/(L)_H$ just below the feed then equals 1.023 which permits heptane to be stripped from the toluene.

The next step is to find the (K)(V)(L)H at the bottom end of the heptanetoluene separation section, that is, just above the lower solvent entry. Using the following equation, which comes from Equation (6), when $\Delta_{ei} = 0$

$$r_{i,n}K_{i,n}V_n - x_{i,n}L_{n+1} = \Delta_i \quad (8)$$

TABLE 2 .- SOLUTION OF EQUATION (8)

æ	K	xK	710.3xK - 555x
0.5	1.42	0.710	237
0.4	1.58	0.632	227
0.3	1.80	0.540	217
0.2	2.11	0.422	189
0.15	2.31	0.346	162.5
0.17	2.23	0.379	175.3

Substitute values of I', L and Δ_i and obtain

$$xK(555 + 155.3) - 555x = 170$$

Find a value of x (and its corresponding K) which satisfies this equation. Table 2 shows that Equation (8) is satisfied with an x between 0.17 and 0.16. Assuming the solvent concentration will reach 0.17 at the feed entry, $(K)_H$ will be 2.02 and $(K)(V)/(L)_H$ will equal 1.934. This high value of $(K)(V)/(L)_{y}$ indicates an easy separation of heptane from toluene in the lower part of this tower section.

The next step is to determine the KV/L values for the solvent below the lower solvent entry. The value of V remains 710.3 (assuming the solvent enters the lower entry at such a temperature that no change in vapor flow rate occurs at that point). L = 555 + 170= 725, $K_a = 2.23$ at the feed entry, $K_x = 3.18$ at the bottom of the tower where x, approaches zero,

At the feed entry KV/L = 2.184At the bottom of the tower KU/L =3.117

This finishes the determination of to KV/L and L/KV factors needed to show that the tower can make the separations specified. Calculation of the number of equilibrium steps required in each section will demonstrate the practicability of the conditions chosen,

Below the lower solvent entry the geometric mean KU/L for solvent stripping

$$\sqrt{2.184 \times 3.117} = 2.61$$

Assume the solvent in the bottoms product is reduced to 0.0001 mole fraction. The vapor rising from the reboiler will have a concentration of $0.0001 \times 3.117 = 0.0003117$ mole fraction

Solvent in bottoms product = $0.0001 \times 14.7 = 0.00147$ mole

Solvent in vapors from reboiler = $0.0003117 \times 710.3 = 0.2213$ mole

Solvent in liquid entering reboiler =

0.2228

The absorption factor corresponding to KV/L = 2.61 is 1.0/2.61 = 0.383. Absorption-factor charts show that just a few equilibrium steps approach the limit of absorption which is 38.3%. Assuming 38% absorption, $0.38 \times 0.2213 = 0.0841$ mole of solvent in the vapor rising from the reboiler which is absorbed and returned in the liquid stream. Hence 0.2228 - 0.0841 = 0.1387 which is the moles of solvent of that entering the top of this section not stripped. The solvent entering the top of this section of the tower (just below the lower solvent entry) amounts to

$$0.17 \times 725 = 123.2$$
 moles

$$\frac{0.1387}{123.2} = 0.00113$$

which is the fraction of solvent not stripped from the liquid entering the tower. Reference to a suitable absorption-factor chart (Fig. 6) shows that 6.7 equilibrium steps will be required to bring about this degree of stripping with a stripping factor of 2.61. If the stripping factor at the top of this section (2.18) were used 8.3 equilibrium steps would be required and if the one at the bottom (3.12) were used 5.7 equilibrium steps would be required. The stripping factor certainly has neither minimum nor maximum values between the ends of this section of the tower hence the true answer must lie between 5.7 and 8.3. The answer 6.7 will probably agree with a step-by-step calculation within the precision with which the absorption-factor chart can be read which is ± 0.1 to 0.2 step.

In the next section of the tower the (K)(V)/(L) values for heptane are farther apart than is safe for this type of calculation. In such cases it is advisable to calculate step by step a few steps away from the end approaching unity. A step-by-step calculation was made throughout the section to give a check on the accuracy of the method. These calculations showed (K)(V)/(L) values for heptane of 1.044, 1.087, and

1.157 respectively for the first three steps below the feed. The (K)(V)/(L) value increases regularly and at an accelerating rate toward the value determined at the lower end of this section. No serious errors will result in using the absorption-factor method for calculating this section.

Ordinarily, having calculated part of the tower by the step-by-step method, only the remaining section of the tower would be calculated by the absorptionfactor method. However, as an example, the whole section will be calculated by the absorption-factor method. The mean stripping factor for heptane is

$$\sqrt{1.023 \times 1.934} = 1.406$$

Assuming no stripping of heptane below the lower solvent entry:

 $\begin{array}{ll} \text{Heptane in liquid leaving stripping section} = \frac{0.07}{14.63} \times 555 = 2.66 \end{array}$

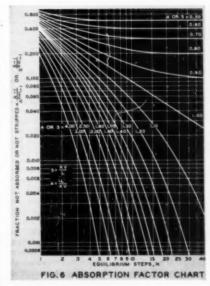
Heptane in vapor entering stripping section = 2.66 - 0.07 = 2.59

The absorption factor for heptane will be 1/1.406 = 0.712. Absorption-factor charts show that twelve equilibrium steps will absorb 70% for this absorption factor. Hence $2.66 - 0.70 \times 2.59 = 0.85$ mole of heptane not stripped from the liquid entering the stripping section. This amounts to $0.85/(0.50 \times 0.85 \times 555) = 0.0036$ mole fraction heptane not stripped. According to absorption-factor charts, 12.9 equilibrium steps are required to give this result

with a stripping factor of 1.406. Stepby-step calculations gave 11.8 stripping steps required. Agreement is only fair between these two values but good enough for most purposes. The absorption-factor method is conservative in this case.

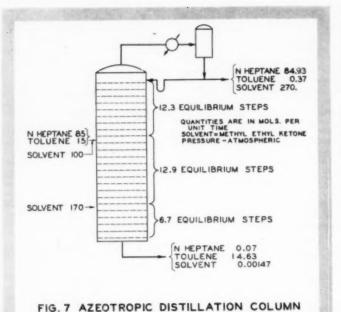
The absorption factor $(L)/(K)(V)_T$ for toluene just above the feed tray is 1.228 and at top of the tower is 1.210. The mean of these values is 1.219. Toluene leaving the bottom of the absorption section is $355 \times 0.5 \times 0.15 = 26.63$ moles/unit time. Toluene leaving in the overhead product is 0.37 mole/unit time. Hence 26.63 + 0.37 = 27.0 moles of toluene must enter the bottom of the absorption section. Since reflux is equal to the total product, the toluene in the reflux will be 0.37 mole. A stripping factor of 1/1.210 = .827 will strip 81% of this reflux toluene in twelve equilibrium steps leaving $2 \times 0.37 - 0.30 =$ 0.44 mole of toluene not absorbed. This amounts to 0.44/27.0 = 0.0163 mole fraction not absorbed. An absorption factor of 1.21 calls for 12.3 equilibrium steps to accomplish this result.

Results of the estimations up to this point are summarized in Figure 7. The number of equilibrium steps in each part of the column has been estimated on the separation of some one component in each section. The number of equilibrium steps in the top section was determined by the number required to absorb the toluene. The number in the section below the feed entry and above





A liquid-liquid extraction unit.



the lower solvent entry was found by estimating how many it would take to strip the n-heptane down to the desired concentration. The number in the section below the lower solvent entry was determined by the requirements for eliminating the solvent from the bottom product. If the absorption and stripping factors apply to one component should they not apply to all components? The very philosophy of this method of calculation demands that all components must obey the same rules. If such is the case, the separation of all the other components must be checked in each section to determine whether the concentrations assumed for these other components can result with the conditions used for the primary calculations.

When a compound is fed into a column at a point where it tends not to concentrate, certain simplifying assumptions may be made. Concentration change of the added component will be slow near the point of entry. (Above entry for a more volatile component, below entry for a less volatile component.) Δ_x approaches zero which permits use of Equation (7) for estimating the concentration of the added component. Δ_x is near zero because the L/RV factor for a volatile compound added at the lower end of a column (azeotropic distillation and certain types of stripping operations) or the KV/L factor for a

relatively nonvolatile compound added at the upper end of a column (extractive distillation and gas absorbers) is much less than unity. Absorption-factor charts show that few equilibrium steps are required to reach the full extent of stripping or absorption when these small factors apply. Hence Δ_x approaches and remains near zero for small values of A or S. This type of approximation was used to establish the solvent concentrations in the azeotropic distillation example.

The L/KV values for heptane in the azeotropic column are 0.626 and 0.500 for just above the feed and at the top of the column using the conditions chosen in the example. The geometric mean L/KV is 0.56 which, with 12.3 equilibrium steps, represents 44% not absorbed. The heptane entering as vapor at the bottom of the tower is 241 moles. Thus $0.44 \times 241 = 106.1$ moles heptane not absorbed. The KV/L factor is 1.00/0.56 or 1.785. With 12.3 steps this corresponds to 0.00032 fraction of the refluxed heptane not stripped or $85 \times .00032 = 0.027$ mole. The product must contain 106.1 - 0.027 = 106.07moles of heptane to correspond with the conditions used. The required product contains 84.93 moles heptane. Even when the larger of the L/KV values is used the possible separation does not agree with the required separation. The

solution obtained was not a true solution because all the components could not be separated in the manner assumed. If a solvent concentration of 0.6 just above the feed entry had been used instead of 0.5 the separation of both components would have agreed with that required within practical limits. A few more equilibrium steps would be needed.

Step-by-step equilibrium calculations showed agreement in the separations Letween the feed entry and the lower solvent entry within 1.1 equilibrium steps in twelve. The KV/L factors for toluene are 0.978 and 0.521 just above the lower solvent entry and just below the feed entry for the conditions used in the example. These S values are far enough apart to give somewhat unreliable answers. The geometric mean stripping factor of 0.714 is equivalent to 31.6% toluene not stripped but the assumed separation would require 41% not stripped. This is an example of a case where the S factor at the top of the stripping section has more effect than that indicated by a geometric average. (Using the average separation factors proposed by McIntire, Shelton, and Hachmuth (37) instead of the geometric means will give close agreement between step-by-step calculations and absorptionfactor calculations even in cases much less favorable than the above example. Use of those average separation factors is somewhat more involved because they are functions of the number of equilibrium steps as well as the terminal conditions of the section of the tower being calculated.)

If rigid adherence to a close agreement between required separation and estimated separation (using average stripping and absorption factors with no weighting for probable end effects) is insisted upon, a solution could have been obtained in the subject example by using a concentration of toluene in the column at the feed entry somewhat greater than in the feed. The over-all results would have been only a little different.

Calculating Extractive-distillation

- Decide upon operating pressure.
 Usually chosen as low as practical. Condenser water temperature frequently determines this pressure.
- 2. Decide upon temperature of liquid phase just above feed entry. This temperature should be as low as the nature of the system will permit. Avoid a temperature low enough to give two liquid phases somewhere in the extractive part of the tower.
- 3. Arbitrarily assign concentrations of non-key components relative to key components in liquid phase just above feed entry. If non-key component has a separation factor intermediate to those of

the key components its concentration should be chosen relatively higher than in the feed. If the non-key component has a separation factor greater or less than the key components its concentration should be chosen relatively less than in the feed.

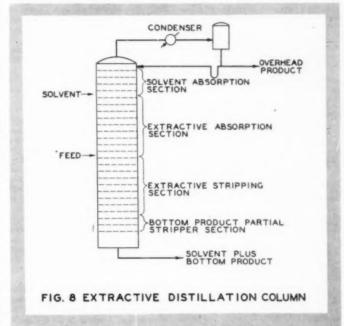
- Choose some solvent concentration and calculate composition of liquid stream just above feed entry (phase equilibrium calculation).
- Decide on over-all division of feed between overhead and bottom products.
 The hoped-for result can be used for a guide.
- 6. Assign a value of unity or somewhat more to LV for the more soluble key component and solve for L and V just above the feed entry. Note that on a solvent free basis the material in the vapor stream minus the material in the liquid stream equals the overhead product (solvent-free). Calculate solvent concentration in vapor phase to be sure it will be considered when the solvent volatility is high enough to have an effect on heat and material balances.
- 7. Decide on condition of feed as it enters column. Is its enthalpy such that it does not change the total moles of liquid passing the feed entry or does not change the total moles of vapor passing the feed entry or does its effect lie intermediate?
- 8. Calculate composition of liquid phase just below feed entry. If the feed enters so as not to change the total moles of liquid passing the feed entry then the composition of the liquid below the entry is the same as above. If some of the feed gees into the liquid phase (and the normal boiling points of the several compounds are nearly the same) assume the composition of that part entering the liquid is the same as that of the total feed. Calculate the new liquid composition and temperature (which will be lower than that above the feed entry).
- 9. Calculate the $\frac{KV}{L}$ value for the less soluble key component just below feed. Note that the K is obtained from item 8. V below the feed equals V above the feed minus that part of the feed coming in as vapor. This KV/L value should be unity or somewhat larger. Although KV/L values less than unity do not necessarily indicate an impossible separation it is best to avoid them. If KV/L value is less than unity introduce more of the feed as liquid but avoid conditions giving two liquid phases.
- 10. Calculate difference between heat content of vapor stream and liquid stream just below feed entry. Latent heats, sensible heats and heats of solution must all be taken into account. Assume temperature of vapor is the same as that calculated for the liquid. Use as a reference plane the temperature of the liquid and assume enthalpies of all compounds zero for the pure liquids at this temperature to avoid the large values that will result from using the enthalpies read from standard enthalpy tables.
- 11. Find solvent concentration and liquid temperature at bottom of stripping section which will give the same difference in heat content between liquid and vapor streams as found just below the feed entry. Use the composition of the desired bottom product to estimate the

liquid composition. Use the same composition (solvent-free basis) for the vapor composition. Use the same temperature for the vapor as for the liquid. This calculation is best made by first calculating a series of equilibrium temperatures for various solvent concentrations. Then, by material balance, the respective V and L values may be calculated from which the enthalpy calculations can be made. Sensible beats, latent beats and heats of solution must all be taken into account.

12. Calculate the KV and KV values for all components (except the solvent) at top and bottom of stripping section and average results for individual components. The geometric mean is preferred to the arithmetic mean for averaging these factors because it gives a more conservative answer.

stream just above feed entry. The temperature of the liquid just below the feed entry should be used as temperature of vapor just above the feed entry. Otherwise follow suggestions under item 10.

- 16. Find solvent concentration and liquid temperature at top of absorption section, which will give same difference in heat content between liquid and vapor streams as found just above feed entry. Use the composition of the desired overhead product to estimate the liquid composition. Otherwise follow the suggestions under item 11.



- 13. Calculate number of equilibrium steps required to reduce concentration of more volatile key component to desired level at bottom of stripping section. See discussion under "Separation Calculations" and the following example for method of calculating the number of equilibrium steps required.
- 14. Calculate fractions not stripped and fractions absorbed for all other components and find amount of each component in bottom product. Unless the choice of conditions was unusually fortunate these results will not agree with those desired. Before trying any changes calculate the absorption section of tower.
- 15. Calculate difference between heat content of vapor stream and liquid

- 18. Calculate number of equilibrium steps required to reduce concentration of less volatile key component to desired level at top of absorbing section. See discussion under "Separatica-Calculations" and following example.
- Calculate fractions not absorbed and fractions stripped for all other components and find amounts of each component in overhead product.
- 20. Tabulate all significant assumptions and results.
- 21. Study table of results and decide which condition to change to more nearly approach a solution. Since the operating pressure is usually fixed by other considerations than the nature of the sepa-

ration it is not ordinarily changed. The temperature just above the feed entry may be raised or lowered to give more desirable results. Avoid conditions that will give two liquid phases. If the non-key components are an appreciable part of the feed their relative concentration just above the feed may need adjustment in the direction suggested by the results. Avoid changing more than one assumption or condition at a time. If too many changes are made, the result will be confusing. Time will be saved by proceeding cautiously until considerable experience has been obtained.

22. Repeat above steps using new set of assumptions and conditions. Tabulate results and compare with first set of results. If the second set of results is not near enough a solution to be satisfactory, choose a third set.

A perfect solution is not necessary or significant since at best it is but an approximation. After two or three trials the calculator will have a good idea of the required number of equilibrium steps, the solvent circulation and the distribution of the nonkey components.

- 23. From the above steps choose or estimate proper solvent circulation, feed condition, non-key component distribution and heat-content differences between liquid and vapor streams and number of equilibrium steps for the two parts of column.
- 24. Estimate reboiler conditions. Reboiler product will consist of net solvent flow plus the other materials yielded as a bottom product. Boil-up must be sufficient to give a heat balance. The number of equilibrium steps required between the bottom of the extractive section of the stripping end of the column and the reboiler may be estimated in the same fashion as in the preceding steps or a step-by-step calculation using both material and heat balances may be made. It is only necessary to approach the conditions calculated for the bottom of the stripping section since extractive separation takes place in the lower few trays as well as in the trays specifically assigned that function.
- 25. Estimate conditions above solvent entry. It is customary to provide several equilibrium steps above the solvent entry to permit absorption and removal of practically all the solvent from the overhead product. Enough of the overhead product nust be returned as reflux to the top of this scrubbling section to give a L/KV for the solvent considerably greater than unity so that the solvent in the vapor may be reduced to near zero concentration in relatively few steps. When this quantity of reflux has been fixed the temperature of the entering solvent is fixed by the heat balance requirement.

Extractive-distillation Example

In the simplified example, the compounds to be separated are cis-2-butene and n-butane with a small amount of 1-butene present to represent a non-key component. In practice the feed to an equivalent extractive distillation tower would contain an amount of the trans-2-butene about equal to the cis-2-butene and minor quantities of butadiene, iso-butylene and perhaps other four carbon atom hydrocarbons. Happel, et al (13) and Buell and Boatright (5) have pub-

lished operating data for industrial installations of extractive-distillation towers separating four carbon atom hydrocarbons.

Another simplification has been the choice of dry furfural as the solvent. The furfural used in industrial C4 separations contains from 3 to 8% by weight water. This water does not change the method of calculation but does complicate it because one more compound must be accounted for. The ratio of water to furfural in the liquid phase changes little throughout the extractive sections of the distillation column and the effect on the phase equilibrium is approximately constant throughout the column provided a separate water phase does not exist in part of the column. When this happens the phase-equilibrium data may be expressed in two ways, one where the water-to-furfural ratio remains constant, the other where the furfural phase is always saturated with water. The proper set of data is used in the appropriate part of the column. The amount of hydrocarbon dissolving in the water phase is so small that its effect on the

A third simplification is the use of a constant pressure throughout the extractive-distillation tower. Industrial columns of this type will have pressure drops of about one-tenth pound per square inch per bubble tray. Since these towers often contain as many as 100 bubble trays the total pressure drop becomes a significant amount and should be taken into consideration, at least in the final calculations.

separation can be ignored.

The phase-equilibrium data, enthalpy data for the pure compounds and heats of solution used in these calculations are based largely on published data (8-10, 17, 21, 36) and only enough data are given to give substance to the calculations.

The feed to the extractive-distillation unit is fixed at 100 lb. moles/unit time and consists of 80, 1 and 19 lb. moles of n-butane, 1-butene and cis-2-butene respectively. In all subsequent calculations, the material quantities given correspond to the rate of flow in pound moles per unit time. Ordinarily the quantities will not be expressed as rates of flow to avoid repetition. However, said quantities in all cases represent rates of flow in pound moles per unit time with the unit time defined as that required to feed 100 lb. moles of feed stock into the extractive-distillation unit.

The numerals identifying the following sections correspond to the enumerated items under "Calculating Extractive-distillation Columns."

 Operating pressure. Butane has a dew point of about 110° F, at 60 lb./sq.in. abs. This is a convenient temperature level for industrial operations. Let 60 lb./sq.in. abs, be the operating pressure for the extractive-distillation column.

- 2. Temperature of liquid phase just above feed entry. The temperature in the upper or absorbing section of the unit will decrease as the top is approached. Butane is not completely miscible with dry furfural at 60 lb./sq.in.abs. when the temperature drops a little below 120° F. A temperature of 130° F, just above the feed entry should avoid separation of a hydrocarbon phase at the top of the absorbing section and still be about as low as safe.
- 3. Concentration of non-key components. Key components in this sepa-ration will be n-butane and cis-2-butene. For those not familiar with the term "key component," the following digression may be of help. A key component in a separation is one of the several components in a mixture to which is assigned arbitrarily some degree of separation from the other components. This degree of separation may be defined in any of several ways, for instance as a certain recovery, as a certain residual concentration in the fraction not containing the larger portion of the key, or as a certain purity of the fraction con taining the larger portion of the key. first two of the above methods of defining separation are safer to use than the last one. Two components may be chosen as keys. All other components will distribute themselves between the two fractions depending on the separation factors for those components and on the chosen separation of the key components. Although it is possible to vary the proportions of the nonkey components in the two product fractions to some extent, it is not possible arbitrarily to assign degrees of separation to non-key components as well as key components and obtain a solution that will agree with the assumptions.

The non-key component in this case has a separation factor intermediate to those of the key components. Its K is 5.17 at a solvent concentration of 0.8 and temperature of 125° F. The corresponding K's for the key components are 6.34 and 3.58. The concentration of 1-buttene in the feed is 1%. Use 2% (on a solvent-free basis) in, the liquid stream just above the feed entry.

- 4. Composition of liquid stream just above feed entry. By trial, a solvent concentration of 0.855 mole fraction was found to give a L/KV for 2-butene above the feed and KV/L for n-butane below the feed of 1.000, or nearly so, when the liquid stream was assumed to be unchanged on passing the feed entry. It was for this reason that this concentration was chosen for the first trial. Subsequent steps 6 and 9 were actually solved simultaneously with the phase-equilibrium calculation to get this starting concentration.
- Division of feed between overhead and bottom products. Twenty moles in the bottom product and eighty moles in the top product were assumed. As shown later a division of about 18.5-81.5 would have been more consistent with the type of separation desired.

6. L and V just above feed entry.

Let L/KV for 2-butene equal 1.002

 $L = 4.325 \ V \ (K = 4.315)$

By material balance

 $0.996\ U - 0.145\ L = 80$

(Concentration of furfural in vapor is about 0.004.)

$$V = 216.9$$
 $L = 938$ $L/V = 4.325$

- Feed condition. Assume feed comes in at such a condition (all vaporized with some superheat) that the size of the liquid stream does not change as it passes the feed entry.
- 8. Liquid composition just below feed entry. Same as just above feed entry.
- 9. $\frac{KV}{L}$ value for butane just below the feed entry.

$$V = 216.9 - \text{feed} = 116.9$$

$$K = 8.06$$

$$\frac{KV}{L} = \frac{8.06 \times 116.9}{938} = 1.005$$

10. Difference of heat content of vapor and liquid streams. This was estimated by assigning the pure liquids at 130° an enthalpy of zero. Latent heats of the hydrocarbons were assumed equal to the latent heats of the individual pure hydrocarbons under saturation conditions at 60 lb./sq.in. abs. The heat of mixing for the hydrocarbons in furfural was estimated from activity coefficient data, using the formula

$$\left(\frac{\partial \ln \gamma_i}{\partial T}\right)_{a,p} = \frac{H'_i - H_i^{\circ}}{RT^{\circ}} \qquad (9)$$

at an x equal to 0.145. The heat of solution for each hydrocarbon was multiplied by its concentration (solvent-free basis) and the results added to give the heat of solution of the hydrocarbon mixture in the solvent. The difference in the heat contents of the two streams was found to be 687,000 B.t.u.

11. Condition at bottom of stripping section. If no heat or material is added to or abstracted from the column from just below the feed entry to the bottom of the stripping section, then the differences between the heat contents, the furfural contents and the hydrocarbon contents of the liquid and vapor streams must be the same at both ends of this section of the column. A solvent concentration of 0.776 and a temperature of 150.7° F. were found to meet the phase-equilibrium and material-and heat-balance requirements.

12. $\frac{\mathbf{KV}}{\mathbf{L}}$ and $\frac{\mathbf{L}}{\mathbf{KV}}$ values for stripping section. The 0.776 value for solvent concentration at the bottom of the stripping section was found by interpolation. To find the V and \mathbf{L} values:

$$\begin{array}{lll} L-V=938-116.9 & (\text{from 9}) \\ 0.224L-0.993V=20 & (\text{furfural}=0.007) \\ L=1034 & V=212.9 & L/V=4.853 \end{array}$$

The butane K for the bottom conditions is 7.34

The butane
$$KV/L$$
 is then $\frac{7.34}{4.853} = 1.512$
The geometric mean butane KV/L is $\sqrt{1.005 \times 1.512} = 1.23$

13. Number of equilibrium steps required in stripping section. The average L/KV value for butane is 0.812. Reference to an absorption-factor chart shows that this factor with fourteen equilibrium steps will give 80.4% absorption of the butane entering the bottom of the stripping section. If the concentration of butane in the bottom of the stripping section.

tom product is 1% and if no further separation between butane and butenes takes place after leaving the extractive section of the stripping column then the butane entering is $0.993\times0.01\times212.9=2.12$. Correspondingly, the butane leaving is $0.224\times0.01\times1634=2.32$. Of this leaving butane $0.804\times2.12=1.70$ moles are absorbed from the entering butane or 2.32-1.70=0.62 mole of butane are not stripped from the liquid entering the top of the stripping section. The butane entering the top of the stripping section was found to be (by calculations not shown) 93.9 moles

$$\frac{0.62}{93.9} = 0.0065$$
 fraction of butane

not stripped. An absorption-factor chart shows that this would result when 16.3 equilibrium steps were used with a stripping factor of 1.23. Sixteen equilibrium steps would give 80.6% absorption of entering butane vapor. The difference between this value and the one found for the estinated fourteen steps is insignificant.

- 14. Net bottom product possible using conditions chosen. The L/KV and KV/L values for 1-butene were found to be 1.005 and 0.995 respectively. These correspond to 94.4% absorbed and 94.0% stripped, respectively. An algebraic solution shows that of the 2.7 moles of 1-butene entering the top of the stripping section 0.10 mole would appear as bottom product. The L/KV and KV/L values of 2-butene were found to be 1.432 and 0.698 respectively. These correspond to 99.91% absorbed and about 69.5% stripped. Of the 39.4 moles of 2-butene entering the top of the stripping section only 11.83 would appear as bottom product.
- 15. Difference in heat content between vapor and liquid streams just above feed entry. This was done in the same fashion as under 10.
- 16. Conditions at top of absorbing section. Phase equilibrium and heat- and material-balance requirements gave a solvent concentration of 0.8795 and a temperature of 123° F. at the top of the absorbing section. The temperature is above the arbitrary lower limit of 120° F. which was set to avoid too close approach to the two liquid-phase regions.
- 17. KV and Kv values in absorbing section. These values were determined in the same manner as for the stripping
- 18. Number of equilibrium steps required above feed.

$$\begin{array}{l} L-V=938-216.9 \ ({\rm from} \ 6) \\ 0.997V-0.1205L=80 \\ V=190.4 \quad L=911.5 \end{array}$$

Assume the concentration of 2-butene in the overhead product is 1.0% and that no further separation takes place among the hardened process of the absorption section. The 2-butane entering the top of this section is then

$$0.1205 \times 0.01 \times 911.5 = 1.10$$
 moles

The 2-butene entering the bottom of the absorption section will be

$$39.4 + 0.01 \times 80 = 40.2$$
 moles

For an absorption factor L/KV = 1.060 the corresponding stripping factor is 0.944.

With twenty equilibrium steps this stripping factor corresponds to 92.0% stripping. Hence $0.92 \times 1.10 = 1.012$ moles of the 2-butene in the vapor leaving the top of the absorption section will be that stripped from the liquid entering the top and $1.10 + 0.01 \times 80 - 1.012 = 0.883$ mole will be residual 2-butene not absorbed from the 40.2 moles of 2-butene entering the bottom of this section.

$$\frac{0.888}{40.2}$$
 = 0.0221 is the fraction 2-butene not absorbed.

With an absorption factor of 1.060 this corresponds to the performance of 21.3 equilibrium steps.

- 19. Amounts of butane and 1-butene in the overhead product. These quantities were calculated using the 21.3 equilibrium steps required by the 2-butene separation and the proper L/KV and KV/L factors.
- 20 and 21. Tabulation and comparison of results. The significant data are tabulated in Table 3 under the heading "First trial." The degree of failure to obtain a true solution is listed as "Discrepancy, % of total." The normal butane in the product streams fails to add up to quantity in the feed by 3.5%. This would not be considered an important difference between the desired and resulting answer. The 1-butene in the product streams amounts to 7.0% more than in the feed. Because the quantity of 1-butene is small, this is not an important difference. The 2-butene misses the desired check by 33.5%. This is too large a discrepancy to be ignored.

It is quite evident that most of the 1-butene will be in the overhead product. If 0.20 mole of n-butane and 0.80 mole of 2-butene are the desired quantities in the bottom and overhead products, respectively, then the feed should have been split about 18.5—81.5

A study of Table 3 suggests that the more effective change would be to increase the amount of 2-butene entering the bottom section of the tower thus forcing more out as bottom product. This could be done by introducing the feed as part liquid thereby increasing the total hydrocarbon entering the bottom section. But this change also increases the V/L ratio in the bottom of the tower, thereby counteracting the desired result.

Another method of increasing the 2-butene entering the bottom of the tower is to increase the total concentration of hydrocarbons in the liquid stream just above the feed entry without changing the temperature at that point. This was done. The concentration of hydrocarbon at this point was increased to 0.16 mole fraction (solvent concentration 0.84). No other changes were made; the same division of the feed was retained as used in the first trial. An L/KV for 2-butene just above the feed of 1.004 was used. With the feed coming in so as not to change the quantity of liquid passing the feed this resulted in a KV/L of 1.068 for n-butane below

TABLE 3.—COMPARISON OF TRIALS CALCULATING AN EXTRACTIVE DISTILLATION COLUMN †

	First Trial	Second Trial
Pressure, lb./sq.in.abs.	60	60
Temperature above feed entry, * F.	130.0	130.0
Solvent concentration at feed entry, mole fraction		0.840
Liquid flow rate at feed entry	938	1005
Solvent circulation rate	801.2	843.2
Hydrocarbon in liquid passing feed entry $ \begin{cases} n\cdot C_x H_{10} \\ 1\cdot C_x H_x \\ 2\cdot C_x H_x \end{cases} $	93.9 2.7 39.4	94.6 3.2 68.0
Solvent concentration at top	0.8795	0.875
Temperature, * F. at top	123.0	121.0
Solvent concentration at bottom	0.776	0.770
Temperature, * F. at bottom	150.7	149.8
Resulting bottom product production rate $\left\{ \begin{array}{ll} n \cdot C_s H_{10} \\ 1 \cdot C_s H_s \\ 2 \cdot C_s H_s \end{array} \right.$	0.20 0.10 11.83	0.20 0.05 16.93
Resulting overhead product production rate $\begin{cases} \frac{n \cdot C_k H_{10}}{1 \cdot C_k H_0} \\ 1 \cdot C_k H_0 \\ 2 \cdot C_k H_n \end{cases}$	77.00 0.97 0.80	75.00 1.08 0.90
Discrepancy. % of total $ \begin{cases} \frac{n\cdot C_a H_{10}}{1\cdot C_b H_n} \\ 2\cdot C_b H_n \end{cases} $	-3.5 + 7.0 -33.5	-6.0 +13.0 -11.4
Equilibrium steps required Bottom	16.3 21.3	14.0 23.5

[†] Flow rates are in pound moles per 100 pound moles of feed.

The significant results of the second trial are also tabulated in Table 3. Two thirds of the discrepancy in the 2-butene has been corrected. The n-butane dis-crepancy is larger. The 1-butene discrepancy is also greater but can be easily corrected by slightly decreasing 1-butene concentration just above the feed entry. The total number of equilibrium steps has not changed. The solvent circulation has been increased about 5%. Unless one is insistent on perfection he could provide for a little more solvent circulation, add a few more equilibrium steps and rest assured the column would adjust itself to make the desired separation or one approximating it.

Phase-equilibrium Data

Many articles have been written on the subject of multicomponent phase equilibria, particularly in the field of petroleum production and refining (20, 23, 24, 26). Earlier correlations, and some of the present correlations of multicomponent equilibrium data, express the equilibrium vaporization ratio, K (sometimes called the equilibrium vaporization constant) for a given compound as a function of temperature and pressure only. Experimental data at high pressures soon showed the effect of the composition of the mixture on the individual equilibrium ratios.

Later correlations (11, 12, 22, 34) applied correction factors, based on the composition of the liquid and vapor phases, to an "ideal" equilibrium vaporization ratio. Composition factors are commonly defined by a summation of

the products of the normal boiling point and the concentration of each component. These correction factors obviously cannot predict the "non-ideal solution" effect often observed when compounds of differing chemical nature occur in the mixture of interest. Smith and Watson (34) include this factor for non-ideal solution effect in their correlation but no one has yet published a reliable method for predicting with any precision the size of this factor.

This non-ideal solution effect may be large. Solvent extraction, extractive distillation and azeotropic distillation make intentional use of this effect to obtain separations not possible or at least difficult by ordinary distillation. The industrial engineer is frequently faced with the problem of making a new separation or a more complete separation between compounds occurring in the various mixtures he must process. A little experience with the difficulty and expense involved in obtaining reliable phase-equilibrium data on ternary or more complex mixtures will make the industrial man conscious of the need for some simple, reasonably reliable method for predicting equilibrium data for those non-ideal systems. Such an approximate method can be used to determine the feasibility of a separation and its probable economic standing. If there is a choice of more than one solvent, the more promising may be picked out. If the separation appears feasible and profitable, determination of more precise phase-equilibrium data can be justified.

Another problem facing the designer

of a separation process working on these non-ideal mixtures is that of correlating and representing the data in a convenient and useful fashion. Temperature and pressure are as important as in more ordinary separations. (Pressure may be ignored in many liquid-liquid extractions but becomes important when one of the phases is appreciably compressible). In addition, the concentration of every component in the mixture has an effect on the concentrations of any one component in the two or more equilibrium phases. (As many as four equilibrium phases may be encountered in certain industrial separations.) The complete representation of such data for mixtures containing more than three components becomes impractically complex.

Many systems of interest to the industrial man may be simplified to one consisting of a solvent (for want of a better term) which is characterized by properties considerably different from those of the remaining constituents, and the latter may be compounds of one class, such as hydrocarbons, or at least compounds which form "ideal" or nearly ideal solutions in one another. Solutions of each of the "related" compounds in the solvent will be quite non-ideal but to differing degrees. As a first approximation, the distribution of any one of the related compounds between two equilibrium phases may be assumed to be a function of the temperature, pressure and concentration of the solvent. The proportions of the other related compounds need not be known to establish the distribution of any one compound between the phases. This simplification is a great assistance in representing multicomponent equilibrium of the nonideal type and, in practice, it is often sufficiently accurate to serve all but the more exacting purposes. John Happel and his coauthors (13) used this method in designing extractive-distillation units. It has worked well in the design of liquid-liquid extraction units separating naphthenes from paraffins or olefins from paraffins. Of course, phase compositions for several typical mixtures should be determined experimentally and compared with the predicted values before any important decisions are made. Often, the predicted values will check experimental values within the experimental uncertainty, which is larger in phase-equilibrium determinations than most technicians realize. If the predicted values differ significantly from the experimental values, a system of minor correction factors, based on the approximate composition of the mixture of related compounds in the solvent-rich phase, may be devised.

The most satisfactory method found by the writer to represent non-ideal bin-

ary data has been the use of activity coefficients. This method of correlation has come into extensive use during the last decade. The interested individual may review the pertinent section, (16, 7, 27, 14) in standard references for a background on this subject. Redlich and Kister (29, 30) give some helpful suggestions on using the activity coefficient for interpreting and correlating experimental data. The activity coefficient curves for a binary system at constant temperature and pressure must obey the Duhem relationships. (See above references.) This characteristic not only gives a means of judging the consistency and accuracy of a set of experimental data but also assists in more precisely correlating such data and helps in interpolating and extrapolating scanty data. Activity coefficients interrelate various equilibrium phenomena such as liquid miscibility, azeotropes, freezing points, vapor pressures and dew points. They will permit estimation of the heat of solution or, conversely, give a means for calculating the change in activity coefficient with temperature from heat of $H'_i - H_i^c$ = differential heat of solution solution data. Mutual liquid solubility data for a series of related compounds in a solvent will give data which can be used to estimate (15, 27) the several sets of binary activity coefficient curves over a range of temperature. The weakness of this method is its dependence on the assumption that the activity coefficient curves will be of the same shape as that given by some activity coefficient correlating equation, usually the van Laar equation. A few vapor-pressure determinations will establish the correctness of such an assumption.

A set of reasonably reliable binary activity-coefficient curves gives the data for calculating the binary phase equilibria. A method, such as outlined, of combining these data permits calculation of multicomponent data. A few experimental multicomponent phase-equilibrium determinations will establish the reliability of the correlation or will provide correction factors to obtain adequate precision. Most extraction processes operate under low or moderate pressures so that fugacities estimated by customary methods (6, 28) are of adequate precision. High-pressure conditions, on the other hand, require considerable experimental data to arrive at safe conclusions.

Conclusion

This necessarily brief discussion of methods for attacking industrial separation problems may suggest ways of solving the wide variety of problems facing the present-day engineer. The concept of basic similarity between the various separation problems will frequently reveal short-cuts in familiar problems and will aid in solving unfamiliar ones. The absorption-factor method is a powerful tool for solving separation problems and can be applied with good results to a wider variety of separations than has been generally

Acknowledgment

The author thanks Phillips Petroleum Co. for permission to publish this article. The particular form of absorption-factor chart used was developed by Frank P. Vance. R. L. McIntire assisted greatly by making the necessary calculations and constructing the charts on Figures 2, 3, 4 and 6.

Notation

$$A = \text{absorption factor} = \frac{L}{KV}$$

F = feed rate, moles per unit

K = phase equilibrium ratio

$$=\frac{y}{r}$$

L = liquid rate = heavier phaserate of flow, moles per unit time

N = equilibrium step number

P = vapor pressure

R = fraction recovery (of a component in a product stream)

R = gas constant, used in Equation (9) only

$$S = \text{stripping factor} = \frac{KV}{L}$$

 $S_F =$ solvent entering with feed, moles per unit time

T = absolute temperature

I' = vapor rate = lighter phase rate of flow, moles per unit time

(A) = absorption factor, solventfree basis = $\frac{\langle k \rangle}{(K)(V)}$

(K) = phase - equilibriumsolvent-free basis = (y)

(L) = liquid rate, solvent-free basis

(S) = stripping factor, solventfree basis = $\frac{(K)(V)}{(V)}$

(V) = vapor rate, solvent-free basis

In = natural logarithm

x = concentration in heavier phase, mole fraction

y = concentration in lighter phase, mole fraction

(x) = concentration in heavier phase, solvent-free basis

(y) = concentration in lighter phase, solvent-free basis

= total pressure on system

a = relative volatility

y = activity coefficient

 $\phi = \text{differential operator}$

 $\Delta_x = \text{change in } x \text{ concentration}$ per equilibrium step

 $\Delta_i = \text{moles}$ i passing a given point per unit time in lighter countercurrenting stream minus moles i passing same per unit time in heavier stream

 $\Delta_{i,j,k}$ = total moles in lighter stream minus total moles in heavier countercurrenting · stream passing a given point per unit time

SUBSCRIPTS:

H = pressure

 $P = \mu$ -heptane

T = toluene

x = concentration

i = component i

j = component j

k = component k

n = equilibrium step number

s = solvent

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The First Hundred Years

Here, as promised in the October issue, "C.E.P." continues to print excerpts from the talks given at the recent Engineering Centennial. We think these terse, provocative paragraphs will enliven engineering thinking, and we hope to make this a continuing feature in the editorial pages.

The Dim Future

Even a casual scrutiny of historical data shows that progress has been sharply decelerating in some technologies and definitely negative in others. In some fundamental categories the rate of Improvement has necessarily become lower and lower as the years pass by. In other categories the rate of deterioration in engineering factors has become higher and higher. We must spend more and more of money, brains, and time to achieve less and less. This curious anomaly is not the fau.. . f the engineer, but is a natural consequence of the physical nature of the world in which we live. There is no escape from the simple fact that we are approaching one dead-end after another.

We are confronted with three kinds of dead-ends. One is imposed upon us by immutable laws of physics and chemistry. Another is concerned with intractable circumstances of geography. The third has to do with finiteness of materials supply. Every physical or chemical operation has a theoretically optimum result which cannot be exceeded. The task of the engineer is to work toward perfection which he can approach but never quite attain. The riper a technology, the nearer the deadend in that particular technology. And

we must be content with existing potential supplies of water-power and fuels. The task of the engineer is to come as closely as possible to the realization of such potentials.

Our greatest engineering opportunity in the future along conventional lines may lie in the mining of coal. Improvements in the early part of the twentieth century were not sensational. Mining is now receiving the technical attention it deserves, and by eventual application of almost fully automatic mining principles we may see far greater improvements in the future than we have seen in the past. In this field we are not yet approaching anything like a dead-end.

Century of Progress in Energy Eugene Ayres

Engineering — Its Definition

It has often been said that God himself was the first engineer and that the first chapter of the book of Genesis confirms this. The second and third verses of the chapter read. "And the earth was without form, and void; and darkness was upon the face of the deep. And the Spirit of God moved upon the face of the waters. And God said, Let there be light: and there was light.'

What I want to emphasize is that the instrument through which the Great Creator began to bring light and beauty and order out of chaos was the spoken word. Please note and I quote again for emphasis: "God said, Let there be light: and there was light."

The record does not specify to whom He spoke. We might suppose it was to the chief engineer of His atomic energy department. At any rate, He got immediate and complete results. And those results followed on the heels of the transmission of a word spoken to some cosmic engineer.

> The Telephone Engineer and His Job Hal S. Dumas

What Manner of Man

2 The chemical engineer is concerned not only with the problem of making chemicals react, but with what means may be used to confine, transport, heat, and cool the reactant and product mixtures; and what costs are going to be, not only to build the plant in the first instance, but to operate and maintain it. In the realm of inorganic chemistry, the chemical engineer has perforce been alert to opportunities to improve the process, particularly with respect to reduction in the amount of equipment required and to opportunities to employ cheaper raw materials, larger units, better materials of construction, better design, better instrumentation, and better control methods. Where it could be justified, continuous processes have been devised to replace batch processes. As new chemical engineering theory developed, it has been applied to the manifold problems associated with inorganic chemical technology.

> Inorganic Chemical Technology -A Miracle of Engineering W. T. Nichols

RECTIFICATION AT REDUCED PRESSURES

Harding Bliss, A. M. Eshaya*, and N. W. Frisch

Yale University, New Haven, Connecticut

R ECTIFICATION in packed towers has been the subject of considerable study in chemical engineering literature, although relatively little work has been done at reduced pressures. Recently Berg and Popovac (1), Hawkins and Brent (4), Peters and Cannon (8), and Struck and Kinney (10) have explored this field and have found, on the whole, somewhat better performance at reduced pressures than at atmospheric pressure. The equipment and run conditions used by these investigators, however, were essentially of the laboratory, and certain factors such as pressure drop and liquid distribution at low rates of flow would be expected to be of considerably more importance in equipment of pilot-plant size.

It was, therefore, the purpose of this work to study vacuum rectifications on a larger scale than heretofore reported and to interpret these studies in the light of chemical engineering theory.

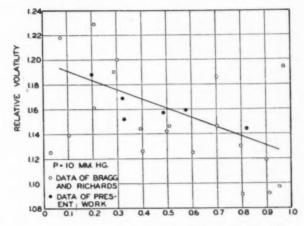
System, Analyses, and Range of Variables

The system orthodichlorobenzene-orthodiethylbenzene (hereafter called O.D.C.B.-O.D.E.B.) was chosen for this work, because it is difficult to separate, typical of the volatility range often met, and easy to analyze by virtue of the density difference of the components, and because some equilibrium data were available.

The rectification studies and equilibrium measurements were made at different times and starting with different original materials. They were purified by careful rectification, however, the first and last cuts being discarded, and were compared as follows:

* Present address: The Coca-Cola Export Corp., New York, N. Y.

Based on a dissertation presented by A. M. Eshaya to the faculty of the Yale School of Engineering in partial fulfillment of the requirements for the Doctor of Engineering degree.



X MOLE FRACTION ODCB IN LIQUID PHASE

Fig. 1. Volatility at 10 mm.

Component	Source	Studies	B.P. range at 760 mm., °C.	Sp. gravity, 30/30	Rectification purification
O.D.C.B.	Dow	Rectif.	179-179.5	3.3974	2-ft. packed column, reflux 20/1
	Eastman	Equil.	179-179.5	1.3973	30 · plate Oldershaw, 10/1
O.D.E.B.	Monanto	Rectif.	180 2-181.2	0.8594	2-ft. packed column, reflux 20/1
	Koppers	Equil.	180.2-181.2	0.8600	30 - plate Oldershaw,

A slight difference may exist between the two samples of O.D.E.B., but it is very doubtful that it is of any significance in rectification studies because of the identical boiling ranges. There are undoubtedly some meta- and paraisomers in these samples, but their proportions should be approximately the same.

Analyses were made by determining the specific gravity of a sample and comparing this with a standard curve of specific gravity vs. composition prepared by mixing known amounts of the pure constituents.

The principal variables covered the following ranges:

Reflux, total; pressure, 16-100 mm. Hg; liquid (and gas) rates, 51-330 lb./ (hr.) (sq.ft.); composition, 0.325-0.556 mole fraction O.D.C.B.

Equilibrium Studies

The vapor pressures of the two constituents (the Dow and Monsanto samples) were determined with a Cottrell apparatus and may be expressed as follows:

O.D.C.B.

$$\log_{10} p = 8.183 - \frac{2380}{T} (54.4-120.3^{\circ} \text{ C.})$$

O.D.E.B.

$$\log_{10} f = 8.615 - \frac{2560}{T} (65.7-123.6^{\circ} \text{ C.})$$

where p is in mm. Hg and T in ^o K.

The foregoing constants were determined by the method of least squares.

The vapor-liquid equilibrium of this system has been measured by Bragg and Richards (2), but their interpretation has been criticized by Carlson and Colburn (3), and certainly there is room for a different interpretation of their data. As a consequence, the equilibrium and T-x data have been redetermined here. The determination was accomplished in an Othmer still (7) slightly modified for vacuum work. The system was evacuated through a dry-ice trap with a Cenco Hyvac pump and the pressure controlled by a Todd vacuum-pressure regulator connected to the system via a surge tank. The results for 10, 50, and 100 mm, are shown in Figures 1, 2, and 3. It is apparent that the results are quite consistent with those of Bragg and Richards, although the present results scatter less. The straight lines are drawn weighing only the points determined in this investigation. It is to be noted that the data are presented as a (defined by

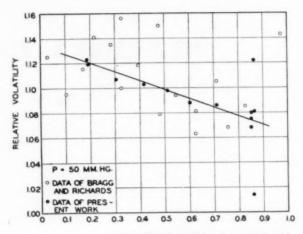
$$\frac{y}{1-y} = a \frac{x}{1-x}$$

vs. composition for different pressures. This is preferable to the ordinary presentation as an x-y curve, because interpolation particularly with respect to pressure was necessary for interpretation of many of the rectification runs made at pressures other than 10, 50, or 100 mm. A large chart was prepared representing the dependence of a on pressure with composition as a parameter, and thus the proper value of a could be read for the interpretation of any rectification run within the range.

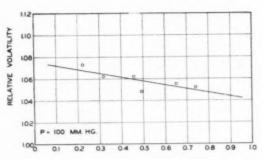
The T-x data are shown in Figure 4 for the 10- and 50-mm. pressure. These data in conjunction with the vapor-pressure measurements permitted the determination of the activity coefficients, and these were checked with the Duhem equation. One form of this is

$$d \log \gamma_{\text{O.D.C.E.}} = \frac{-(1-x)}{x} d \log \gamma_{\text{O.D.E.B.}}$$
(3)

which indicates that a plot of the activity coefficients on a logarithmic scale

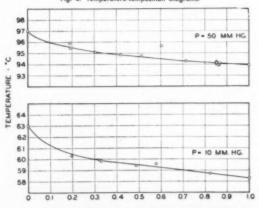


X MOLE FRACTION ODCB IN LIQUID PHASE Fig. 2. Volatility at 50 mm.



X MOLE FRACTION ODCB IN LIQUID PHASE Fig. 3. Volatility at 100 mm.





should have a slope of -(1-x)/x. A comparison between these values and actual slopes is shown below:

æ	-(1-x)/x	Slope at 10 mm.	Slope at 50 mm.
0.25	-3.0	-3.0	-2.8
0.5	-1.0	-0.5	-1.06
0.75	-0.33	-0.37	-0.28
0.85	-0.18	-0.24	-0.13

The agreement is thus good, although it should be noted that disagreement became more noticeable below x = 0.2. Only one or two rectification runs, however, were made below x = 0.2.

Apparatus and Rectification Studies

The general setup of the experimental equipment is shown in Figure 5. The system was so constructed that the distillation column proper could be removed and changed for the investigation of different

types of columns.

The first column studied was an ordinary packed tower made of a 6-ft. section of 3029-in. I.D. brass pipe. The packing used was ½-in. carbon Kaschig rings. The attempt was thus made to get away from small laboratory-size columns and packings in the hope of securing data applicable to larger scale design. This packing has 73% free volume and 10,200 pieces/cu.ft. The packed section was 63 in. high and was supported on a wire screen. An ordinary shower-type reflux distributor was installed on the top of the packed section. Before installing it in the experimental column, the reflux distributor was supported on Raschig rings and its operation observed. The distributor was shown to provide even and satisfactory spreading of the reflux stream.

The second tower used was 40 in. long and 3.029 in. in diameter and was packed as follows. Small hollow cylinders of \$\frac{6}{64}\text{-in.}\$ brass, covered on top and flared at the bottom, were strung on a copper wire at 2-in. intervals. Each piece, or "bell," was \$\frac{1}{16}\text{ in.}\$ in. long, \$\frac{7}{16}\text{ in.}\$ in diameter at the top, and \$\frac{5}{2}\text{ in.}\$ in diameter at the bottom. Many strings were suspended in the column so that the bells were staggered as shown in Figure 6. These strings were held taut between supporting plates, and the whole assembly was slipped into the column. The liquid distributor was made up of a plate with 32 \$\frac{1}{2}\text{-in.}\$ hules containing \$\frac{1}{16}\text{-in.}\$ copper tubes, as shown in Figure 6.

Heat was supplied to the still pot by a 2-kw. electric heater. The power input to the heater was controlled by a 4.5 K.V.A. Varitran. The energy input during each run was measured by an integrating pre-

cision watt-hour meter.

The reflux stream was measured by one of two rotameters with ranges of 10 to 60

and 20 to 250 cu.cm./min. respectively.

Absolute pressure in the still pot was measured by a closed-end U-tube mercury manometer. Pressure drop was measured by an ordinary manometer filled with dibutylphthalate. Pressure regulation in the system was accomplished in two steps. First an approximate adjustment was made by opening or closing a bleeder needle valve. The final adjustment was made by a conventional float-type mercury manostat. In this way the pressure during any one run was maintained constant to ±0.1 mm. Hg.

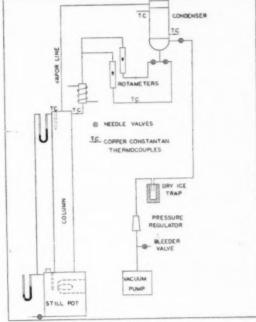


Fig. 5. Equipment.

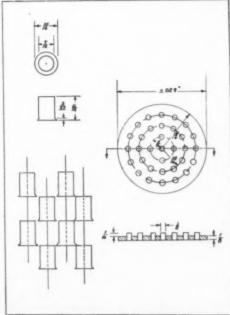


Fig. 6. Details of bell packing.

All temperature measurements made by means of copper-constantan thermocouples. The thermocouple electromo-tive force was measured with a type K potentiometer and a No. 2500 moving-coil galvanometer. Temperatures measured to better than 0.1° C. could be

The quantity of water going through the condenser was measured by a set of cali-

brated orifices.

The whole system except the bottom of the still pot was carefully insulated with a layer of felt insulation 1/2 in. thick. As the heat balances showed, this was sufficient to keep the average heat loss below 8% of the heat input, and since the major portion of this must have been through the uninsulated still-pot bottom the column operation was essentially adiabatic.

Procedure

At the beginning of every run the column was operated for about 30 min. at a rate approaching flooding. This was done to ensure complete wetting of the packing in all runs. Then the heat input was decreased and regulated to the desired rate of boil-up, and the pressure adjustments were com-pleted. The column was then allowed to run for about 3 to 4 hr. in order to obtain equilibrium. When equilibrium was indicated by steady temperature and pressure readings, samples were taken from the still pot and from the reflux-return line. A rectification run lasted usually between 4 and 5 hr.

Data and Interpretation

The rectification performance of the two columns was interpreted in terms of Hog and Kga. Since each run was at total reflux and with a constant value of a (because of the low pressure drop and small composition change), the analytical expression for H_{00} was used:

$$N_{\theta\theta} = \frac{2.303}{a - 1} \log \frac{y_{\theta}(1 - y_{1})}{y_{1}(1 - y_{\theta})} + 2.303 \log \frac{(1 - y_{1})}{(1 - y_{\theta})}$$
(4)

$$H_{oq} = \frac{Z}{N_{oq}} \tag{5}$$

$$K_0 a = \frac{G_m}{H_{000}}$$
(6)

Because of the marked dependence of a on pressure, those runs with pressure drop through the column in excess of 4 mm, were considered nonisobaric and were not calculated.

The results are given in Tables 1 to 6* and Figures 7 to 10.

Discussion of Results

The following discussion treats essentially only the 3/2-in.-ring-packed tower,

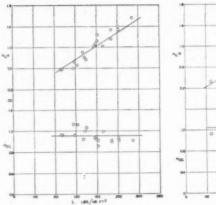


Fig. 7. How and Kop at 49.8 mm.

Fig. 8. Hac and Kea at 33.8 mm.

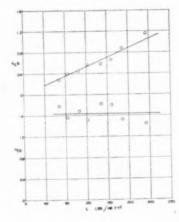


Fig. 9. Hog and Koa at 18.5 mm.

because the runs with the bell-shaped packing were so few in number. Results between the two, however, were com-

It is clear, on inspection of the tables and figures, that H_{00} is essentially independent of composition, as would be expected, since the diffusional properties of these materials do not differ greatly.

Effect of Rate. The data of Series A, B, and C (Tables 1 to 3*; Figures 7 to 9), in which a fourfold variation of gas and liquid rates was involved, show that the rate of flow has no effect on the value of $H_{\theta\theta}$ or that $K_{\theta}a$ is linear in rate. The only reasonable explanation for this, in the authors' opinion, is that an increase in flow rate produces merely an increase in the a term of $K_{\theta}a$; that is, the packing is wetted more com-

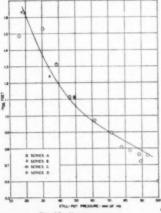


Fig. 10. Hog vs. pressure.

^{*} Supplementary data (Tables 1-6) are on file (Document No. 3718) with American Documentation Institute, 1719 N St., N.W., Washington 6, D. C., obtainable by remitting \$1.00 for microfilm and \$1.80 for photocopies.

pletely. All flow rates in this work were quite low to avoid flood or excessive pressure drop at the high linear gas velocities involved. Pressure drop was not above 4 mm. in all reported runs. Probably Hoo would have been improved had higher rates been attained. Such low flow rates are not a limitation on the utility of the work, however, since these same aims would be sought by anyone carrying out distillation in this pressure range. This increase in wetting with increased flow rate was qualitatively confirmed by observations in a glass tower comparable to the experimental one and by the work of Mayo, Hunter, and Nash (5).

Effect of Pressure. The marked dependence of H_{00} on pressure is shown in Table 4 and Figure 10, on which the data of Series D and the averages of Series A, B, and C are plotted. The solid line represents this dependence, as determined by the method of least squares, the equation being

$$H_{00} = 6.52 p^{-0.47} \tag{7}$$

with H_{00} in ft. and p in mm. Hg. If one recalls Equation (6)

$$H_{00} = \frac{G_{\rm m}}{K_{\rm G}a}$$

and the well-known relation

$$\frac{1}{K_G a} = \frac{1}{k_G a} + \frac{m}{k_L a} \qquad (8)$$

it is clear that with enough data one should be able to resolve the measured $K_{0}a$ into its components, $k_{0}a$ and $k_{L}a$. However, the j-factor correlation indicates that

$$\frac{k_{a}}{G_{m}} \left(\frac{\mu}{\rho D}\right)^{\frac{\kappa}{20}} = \frac{f}{2} \tag{9}$$

or, in other words, that at a constant flow rate kga should be affected by pressure only if $(\mu/\rho D)$ is so affected. Of course, the Schmidt group is not so affected, being essentially independent of pressure. In short, this effect cannot be explained by an analysis of koa. In turning to k,a, it seems hardly conceivable that pressure could affect any liquid property to this degree. We have therefore concluded that the measured and important effect of pressure is not that at all but, in truth, the effect of the temperature accompanying change. However, for the gas film the Schmidt group varies only to a small degree with temperature. Thus, since there is a big effect of temperature which should not occur if the gas film were of controlling importance, we conclude that this is a case of liquid-film control.

Since the temperature effect is so important, it would be wise to transform

Equation (7) into one expressing H_{pq} as a function of T. This is most simply done by rewriting Equations (1) and (2) for the vapor pressures in the following approximately

$$\dot{p} = \beta T^n \tag{10}$$

in which n (average for the two substances) = 15.3. Therefore Equation (7) becomes

$$H_{00} = \gamma T^{-7.2}$$
. (11)

We may then write the well-known equation

$$H_{00} = H_0 + \frac{mG}{L}H_L \qquad (12)$$

and observe that G/L is 1.0 (since reflux is total), m is approximately 1.0 (since separation is very difficult), and H_0 is 0 (since gas-gas film is unimportant). We must conclude, therefore, that our Hog results are equivalent to H_L , or

$$H_L = T^{-7.2}$$
 (13)

This is in very good agreement with the results of Sherwood and Holloway (9), since their value for the comparable exponent for temperature effect may be shown to be -6.8. Agreement between these results and Sherwood and Holloway in absolute magnitude (as distinct from temperature dependence) is not very good, but this is not surprising, since the flow rates used here had to be much less than theirs.

The results of this work are in disagreement with those of Berg and Popovac (1), Struck and Kinney (10), Peters and Cannon (8) and Hawkins and Brent (4), although most of this work was at pressures below those used by most of the others. All these investigators found much smaller, i.e., better, values of H_{00} , or H.E.T.P. (about 3 in. at or near 20 mm.), and much less effect of pressure (temperature). The latter observation is probably explained on the basis of differing relative importance of gas and liquid films among the different systems used. With essentially complete liquid-film control, as was the case here, a big pressure (temperature) effect is

diameter, relatively short columns. The present investigation was carried out in a 3-in. diam. column (the largest of the others was 2 in., that of Peters and Cannon) 51/4 ft. long (twice the longest of the others). Channeling under these conditions must be more severe (indeed, observations on the effect of L on a of Kgs confirm this) than with smaller, shorter columns. Since the present column approaches in size much more closely a commercial column, where channeling would also be expected, it would appear that these more conservative results should be given considerable weight in design. Channeling is also indicated in the observed pressure drop. Despite the fact that the flow rates were quite comparable, the pressure drop was much greater in the case of Peters and Cannon (8) than in this work, although the packings were considerably different. It is probable that the primary effect of the excellent packing used by these workers was that of breaking up the liquid film, with the incidental result of higher pressure drop. This would cause the major resistance to be offered in the gas phase and would bring about the results found, namely, better performance and much less effect of pres sure and temperature. However, low pressure drop is often vitally important in commercial columns or the advantage of the vacuum may be partly lost, and it was for this reason, as well as because of the rather large effect of pressure on relative volatility in this system, that the apparatus was operated at low pressure drop.

Optimum Pressure of Distillation

Since the ease of separation is better at low pressure and Hoo is less at higher pressure, it is obvious that an optimum pressure for distillation should exist. is easily solved as follows:

Equation (5) shows that

$$Z = H_{00} \cdot N_{00} \qquad - \tag{5}$$

Our results show that H_{og} is dependent on pressure as follows:

$$H_{og} = \beta p^a. \tag{7}$$

 N_{og} is given by Equation (4), and therefore

$$Z = \beta p^n \left[\frac{2.303}{\alpha - 1} \log \frac{y_o(1 - y_1)}{y_1(1 - y_o)} + 2.303 \log \frac{\sqrt{1 - y_1}}{(1 - y_o)} \right].$$

For a given separation, yo and y1 are to be expected, but with gas-film control, constant; so practically no effect would be expected. The discrepancy of absolute magnitudes is a much more serious observation, and

> The term a-1, according to the equilibrium results presented here, is approximately linear in the square root of

 $Z=\frac{\beta'p^n}{n-1}.$

since flow rates and packing sizes were quite comparable at least in some cases, only one explanation seems possible. All

the foregoing investigators used small-

(14)

pressure, and the equation for this at x = 0.5 is

$$a-1 \stackrel{\bullet}{=} 0.207 - 0.015 p^{\frac{1}{2}}$$
. (15)

This will be slightly different for other values of x, but the change will not be great.

Substituting Equation (15) in (14),

$$Z = \frac{\beta' p^n}{0.207 - 0.015 p^{\frac{n}{2}}}, \quad (16)$$

Observing that n = -0.47, differentiating and setting equal to zero for the minimum Z, one finds that the optimum pressure is 44 mm.

This value will depend on the particular system of course, but it may be noted that Myles, Feldman, Wender, and Orchin (6) found such an optimum at about 200 mm. for the system n-dode-cane-cyclohexyl pentane.

Conclusions

The system orthodichlorobenzene-orthodiethylbenzene exhibits a considerable dependence of relative volatility, a, on pressure and a slight dependence on composition. Such values were determined over a good range.

Using these values of \mathfrak{a} , the results of 48 rectification runs in a packed tower (½-in. rings) at pressures of from 16 to 100 mm. have been interpreted. These results have been expressed as H_{0G} and K_{0G} . It is shown that composition and flow rates have negligible effects on H_{0G} over the range but that pressure has a very great effect.

This pressure effect is given by the

$$H_{00} = 6.52p^{-0.47}$$

with H_{00} in ft. and p in mm. of Hg. The foregoing pressure effect is shown to be, in truth, the influence of the temperature change which necessarily accompanies a change of pressure in a distillation column. The temperature dependence may be expressed as

$$H_{00}=\beta T^{-7.2}.$$

When it is observed that this is undoubtedly a case of liquid-film control, the agreement between the temperature dependence found here and that of Sherwood and Holloway (9) on liquid films in absorption is very good. Comparison of distillation results is difficult because of the differing relative importance of the two films with different systems and because of different diameters and lengths of columns.

It is shown that, since a is unfavorably influenced by an increase of pressure and $H_{\partial\Omega}$ favorably influenced, there not be an optimum pressure of rectification, i.e., one to give a minimum tower

height. This is 44 mm. for this system, but it would be expected to depend on the system and on the packing.

Notation

a = area per unit volume of packing, ft.-1

G = gas-flow rate, lb./(hr.) (sq.ft.)

 $G_{\rm m} = {\rm gas}$ -flow rate, moles/(hr.) (sq.ft.)

 H_{00} = height of a transfer unit, based on over-all driving force in gas phase,

 $H_G = \text{same}$, based on film driving force in gas phase, ft.

 $H_L = \text{same}$, based on film driving force in liquid phase,

H.E.T.P. = height equivalent to theoretical plate, ft.

> j = mass transfer - fluid friction correlation factor

K_Ga = transfer coefficient, based on over-all driving force in gas phase, lb. moles/ (hr.) (cu.ft.) (mole fraction)

 $k_0 a = \text{same}$, based on film driving force in gas phase, preceding units

 $k_L a = \text{same}$, based on film driving force in liquid phase, preceding units

L = liquid rate, lb./(hr.)(sq. ft.)

m = slope of equilibrium linen = exponent

 N_{OG} = number of transfer units based on over-all driving force in gas phase

p = pressure, mm. Hg

 $T = \text{temperature}, \circ K.$

x = mole fraction of more volatile component in liquid

y = mole fraction of more volatile component in vapor

Z = tower height, ft.

a = relative volatility

 $\beta.\beta' = constants$

γ = activity coefficient, and also a constant

 $\frac{\mu}{\rho D}$ = Schmidt group

Subscripts:

o = still bottoms1 = distillate

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Discussion

D. P. Murch (Givaudan Corp., Little Falls, N. J.): Is it possible that your higher h.t.u. values are due to the fact that the ratio of column diameter to packing diameter is only 6:1? We know that it is very important to get that ratio up to 8 or 10, especially in vacuum work where the liquid rate is very low and the effect of poor distribution is accentuated.

N. W. Frisch: I believe that may account for a portion of the large value of h.t.u. Naturally, we had to have this packing of large diameter to minimize pressure drop, but I believe the effect of the small ratio 6:1 instead of 8:1 or 10:1 would contribute only slightly to the high values of h.t.u.

ENERGY DEMANDS

2 Can we feel altogether comfortable about the rising tide of our energy demand? I do not think so, for in spite of our accelerated rate of industrialization we have begun to lose ground to the rest of the world. It has been pointed out that while our per capita use of petroleum compared with the per capita use of the rest of the world rose consistently over the earlier portion of the twentieth century, a peak was reached in 1930. In that year we consumed thirty times as much per capita as the rest of the world. Since that time the factor has declined steadily, year by year. Now the factor is seventeen and the trend is still inexorably downward. In other words, while we are moving forward at a great pace, the rest of the world is moving forward much more rapidly than we are.

From Century of Progress in Energy by Eugene Ayres Given at Centennial of Engineering

Performance of Perforated-

Plate Distillation Columns

D. S. Arnold, C. A. Plank, and E. M. Schoenborn

North Carolina State College, Raleigh, North Carolina

DESPITE the fact that perforatedplate or sieve-plate columns have been in use in the chemical industry for many years, very little information has appeared in the literature upon which to base sound design or to predict performance under various operating conditions. The preference displayed for bubble-cap trays is probably attributable to certain reported disadvantages for perforated plates. It has been pointed out (2), for example, that such plates operate properly only over a limited range of liquid and vapor flows, that plates must be perfectly level, and that if corrosion causes hole size to increase, plate efficiency is reduced. The trend toward use of improved methods and materials of construction together with design for particular capacity and performance duties would tend to minimize such disadvantages in numerous applications. Economic considerations, on the other hand, would favor consideration of such columns since the potential value of extended application of perforatedplate units in distillation and absorption operations lies in the lower cost of plate fabrication and installation in comparison with conventional bubble-cap assemblies.

In operation, perforated plates differ essentially from bubble-cap plates in that vapor-liquid contacting is simply attained in the former by virtue of the gas or vapor bubbling up into the liquid through a large number of small holes in the plate rather than through the slots of a number of bubble caps. In order that an appropriate depth of liquid be maintained on the plate during normal operation, downflow pipes and weirs are usually provided in a manner similar to that for bubble-cap trays. In the case of perforated plates, however, this depth of liquid must also be maintained by virtue of the flow of gas or vapor through the holes; otherwise, liquid will drain through them with a resulting decrease in bubble action and efficiency. For any given plate layout and operating condition, therefore, there exists a To obtain information on perforated-plate behavior, studies were carried out using air and water in a 15-in. I.D. glass-walled column containing three plates spaced 18 in. apart. Perforation diameters varied from 0.059 to 0.373 in. and free-space ratios from 3.9 to 11.4%. Downflow weir heights of $\frac{1}{2}$, 1, 2, and 4 in. provided corresponding liquid seals. Pressure-drop data were obtained for water-mass velocities ranging from 0 to 2700 and for air rates from 70 to 900 lb./(hř.)(sq.ft. of column cross section), respectively.

Over the range of variables studied, pressure drop due to the dry plate (L = 0) was proportional to the 1.8 power of the gas velocity and was correlated by a monification of the orifice equation. With liquid flowing across the plate, limiting air velocities were established above which no leakage through the holes occurred. Below these velocities operation is unstable since not all perforations are bubbling.

In the region of stable operation investigated, it was found that the total measured pressure drop could be predicted approximately by application of an empirical correction factor to the sum of the dry-plate pressure drop and the static liquid seal. Application of the data to design is discussed.

minimum gas velocity and corresponding pressure drop below which stable
plate operation ceases. As in the case
of bubble-cap trays, an upper limiting
vapor velocity exists where flooding
occurs or where entrainment becomes so
excessive as to reduce efficiency. It is
important, therefore, that perforated
plates be designed so as to operate in
the stable region if optimum performance is to be obtained.

Accurate prediction of either bubblecap or perforated-plate behavior is complicated by the large number of variables which must be considered. While considerable progress has been made in recent years with respect to bubble-tray behavior, unfortunately very little information has been made available concerning the perforated plate. In an effort to provide data useful for initial design purposes and to obtain some understanding of perforated-plate behavior, it appeared desirable to undertake exploratory studies using a simple system such as air and water in an experimental column specifically designed for the purpose. This paper describes briefly results of measurements of pressure drop and of plate stability as a function of number and size of perforations, static liquid seal, and gas- and liquid-flow rates. Included also are measurements of pressure drop through dry plates since such data may be useful in predicting over-all pressure drop through a column operating with various liquid loads. The small diameter of the column (15 in. I.D.) used in this investigation in comparison with large commercial units precluded the determination of the effects of hydraulic gradient, although it is appreciated that this factor is an important consideration particularly where high liquid loads are encountered in practice.

Experimental Column

Because no suitable data were available on which to base a preliminary design, a brief survey was first made of the essential features of several experimental hubble-cap units for which performance data have been published. Of those studied, the column of Peavy and Baker (14) and that described by Grohse et al. (4) were arbitrarily selected as a basis for construction of the present unit. In addition, a small 10-in. diameter perforated-plate column was built

TABLE 1 .- COMPARISON OF COLUMN LAYOUTS

		Peavy and Baker (14)	Grohse et al. (4)	N. C. state, 10 in.	N. C. state, 15 in.	Gunness and Baker (8)
1.	Inside diameter of column, in	18	13	XO	15	66
2.	Bubbling devices	3-in. caps	1% in. caps	1/16 in, holes	1/16- to %-in.	%-in. holes
3.	Liquid path, in	12.3	7 %	10=	9.54	22 (and up)
4	Vapor-liquid contacting sone (% of column area)	6856	73.76	80 %	59%	88%
8.						1000
	area)	9.4%	11.7%	0.8%	(a) 4%, (b) 11%	14.5%
6.	Static liquid seal, in	0 to 3	2 %	0 to 4	0 to 4	2 1/2
7.	Plate spacing, in	6, 12, 18	24	12 1/4	19	16
8.	Downflow weirs	segmental (with a splash baffle)	segmental (no cap slots facing weir)	1 1/2 in.	segmental (with a splash baffle)	4- and 8-in, circular pipes
9.	Downpipes	Two 1 1/2-in. pipes	segmental	1 % in. tubing	1 ½ in.	aix 4- and three 9-in. pipes (ak.)
10.	Operating range reported (based on column area) (a) Superficial vapor velocity, u,					
	ft./sec.	0.4 to 4.5	0.3 to 3.5	0.04 to 0.2	(a)>2.5, (b)>4.5	2.3 and 2.6
	(b) F factor	0.1 to 0.9	0.1 to 0.9	********	(a)>0.4, (b)>0.9	0.54 and 0.61
	(c) Vapor mass flow rate G, lb./					
	(hr.) (sq.ft.)	100 to 1000			(a)>400, (b)>900	
	(d) Reflux ratio, L G	0.7 to 1.0	6.4 to 12.5	3 to 60	0.5 to 6.8	0.7 to 5.5
	the second secon		The second			

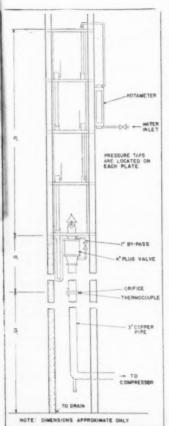


Fig. 1. Diagram of experimental perforatedplate column.

and operated in these laboratories to gain some background of experience in the performance of such units. Essential layout features of these columns are given in Table Salient features of the column described by Gunness and Baker (5) are also shown to provide some measure of comparison with a commercial column. In general, it was desired that the experimental unit be made as flexible as possible yet provide free-space ratios of approximately the same magnitude as those of bubble-cap columns of comparable size. (In this paper, free-space ratio is defined as the ratio of total perforation area to empty-column cross-sectional area and is analogous to the ratio of total slot area to column cross section for bubble-cap trays.)

The column was made up of four 15-in. I.D. Pyrex-glass cylinders each 18 in. high. Three identical plate assemblies and two end sections were mounted on tie rods and suspended inside a steel framework, as shown in Figure 1. An overhead view of the column in operation is shown in Figure 2 A diameter of 15 in. was selected because this was the largest standard-size glass cylinder available and because it provided a cross-sectional area convenient for the gas and liquid flows that could be satisfactorily handled in the laboratory. A glass-walled column was chosen in preference to other materials of construction so that plate per formance might be visually studied at all times, and construction was such that the entire column could be disassembled easily and rapidly to provide for the necessary changes in plate layout. A plate spacing of 18 in. was used since adequate headroom was available and so that the column might be operated at high gas and liquid loads without flooding. Although the present experimental setup was arranged for initial study of the air-water system, it was designed so that subsequent efficiency studies might be carried out by actual distillation or absorption operations upon addition of the necessary auxiliary equipment. Use of three plates was dictated by the desire to eliminate end effects and at the same time operate with a minimum of plates.

Details of the plate assembly are shown in Figures 3 and 4. To observe the effect of variation of hole diameter and free-space ratio, the assembly was made of two principal parts. That part of the plate which had features common to all runs (except where changes in weir height are noted) was made of \(\frac{4}{2} \)-in-thick brass sheet to

which was welded, soldered, or bolted the segmental baffles, downflow pipes, pressure taps, etc. The center section of the plate was carefully machined to accommodate a series of stainless-steel perforated inserts. Data for the inserts used are summarized in Table 2, with a typical set being shown in Figure 5. Stainless steel was chosen for these inserts to preclude changes in hole diameter as a result of corrosion or fouling during prolonged periods of operation. Plate thickness was eliminated as a variable since all units were similarly made of 24 gage sheet (0.029 in. thick). In general, all perforations checked were uniformly round, of constant diameter, and free of burrs or other imperfections. Although inserts were punched without margins, edge perforations were easily blanked by the rubber gasket

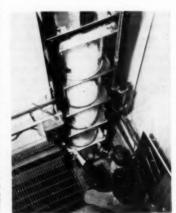


Fig. 2. Overhead view of 15-in. perforatedplate column in operation.

Segmental-type overflow weirs were selected to provide single cross flow of liquid on the plate since it was believed this would be representative of industrial practice. Weirs were installed at the inflow end of the plate to reduce flow irregularities from the downcomer from the plate above as well as to provide a more nearly uniform velocity profile across the plate. To permit a study of the effect of liquid depth or static liquid seal on the plate, a series of removable weir plates ½, 1, 2, and 4 in. in height was made and bolted to the weir aggments to produce corresponding outflow weir heights as desired.

Many literature references demonstrate the need of a device for minimizing splashing and surging of liquid over the outflow weir of the plate. The importance of the use of a splash baffle has been discussed by Peavy and Baker (14). The problem was also recognized by Kemp and Pyle (9) and Hutchinson, Buron, and Miller (6), who used extensive calming sections instead of baffles. Kirschbaum and Andrews (10) discussed the effect of liquid splash-over, and the work of Kamei, Takamatsu, and Umeshita (7) indicates similar difficulties. Gerster et al. (3) and Grohse et al. (4) blanked off the slots of the bubble caps which faced the downflow weir to reduce the splash-over. Applications to other columns of the results of work by Nandi and Karim (8, 12) and Kamei, Takamatsu, and Umeshita (7) are hampered by the problem of determining an appropriate liquid-seal value. Use of a suitable splash baffle might have alleviated this problem.

This surging and splashing of liquid over the outflow weir was minimized by installing a splash baffle [suggested by Pyle (17)] as shown in Figures 3 and 4. This baffle was mounted at a distance from the weir face and above the top surface of the plate in such a way as to minimize liquid-pressure drop and hydraulic gradient between the contacting zone and the outflow weir. Tests made during the investigation demonstrated that this end was achieved. Leakage of liquid around the weirs and baffles was reduced by inserting thin rubber gaskets between them and the column wall. Failure to prevent such leakage or to use a splash baffle frequently resulted in erratic behavior during test.

Pressure drop across each plate was measured by means of an inclined man-



Fig. 4. Perforated-plate assembly.

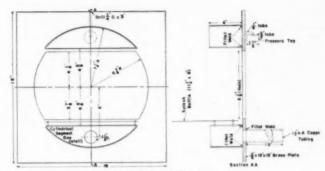


Fig. 3. Perforated plate detail.

TABLE 2 .- DATA FOR PERFORATED INSERTS

Insert	Hele diam.,	Free space, column, %	Free spa insert,		Hole spacing, in.	Total perf. area, sq.in.
I-1	0.038	4.3	7.2	square	0.125	7.56
1-2	0.059	3.9	6.6	triangle	0.218	6.94
1-3	0.139	4.5	7.5	triangle	0.482	7.88
I-4	0.250	4.5	7.5	triangle	0.87	7.88
1-5	0.312	4.1	6.9	triangle	1.125	7.25
II-1	0.083	10.5	17.7	triangle	0.198	18.6
II-2	0.177	12.0	20.2	triangle	0.375	31.2
II-8	0.285	11.9	20.1	triangle	0.500	21.1
II-4	0.276	11.5	19.4	triangle	0.934	20.4
111-1 111-2 111-3 111-4 111-5	0.039 0.062 0.144 0.249 0.309 inserts were mad	18.5 17.1 17.6 17.4 16.2 de of 24 gage,	31.1 28.8 30.1 29.4 27.4 (ype-316, 1	square triangle triangle triangle triangle punched stainless-steel	0,063 0,11 0,25 0,437 0,568 sheet, 0,029	32.8 30.2 31.6 30.9 28.8 in. thick.

emeter connected to a static pressure tap as shown in Figure 3. A ½-in. hole was drilled into each brass plate just beneath the inflow weir so that connection might be made without interference with the glass wall of the column. A ¾-in. copper tube closed at the upper end and placed over the pressure-tap entrance prevented liquid from entering the system during operation. Furthermore, any entrained liquid dripped readily off this tube.

Air from a compressor entered the lowest plate of the column through a long length of vertical pipe, was metered with a standard sharp-edged orifice, and was controlled by means of a plug cock arranged with a small by-pass connection. In this way air-flow rates were easily varied and reproduced. An inverted cone located at the exit of the air duct reduced any jet action of the air entering the first plate, while a funnel mounted above the entire opening prevented entry of water into the air-supply system. Water from a calibrated rotameter was introduced to the top plate over an inflow weir similar to those employed on the remaining trays.

Experimental Procedure

Since the perforated plate itself contributes in large measure to the total pressure drop through the plate during normal operation, initial measurements were made of the pressure drop due to the dry plate alone. This was simply accomplished by noting the pressure drop across any plate as the air-flow rate was varied with no liquid flowing. It is of interest to note in this connection that the pressure drop across each of the two top plates containing similar inserts was identical. Pressure drop across the lowest plate in the column difference of the top the plate in the column difference of the two top plates containing similar inserts was identical.

fered slightly, however, from that across ahe other two probably because of nonuniform velocity distribution induced by the entering air duct. In several experiments inserts were interchanged between plates, but no significant difference in pressure drop was observed. These results attested to the uniformity of the perforations and plate layout and indicated that performance of a given set of inserts was reproducible.

Because the volumetric capacity of the blower was limited by its characteristics, extremely high air velocities could not be obtained, especially for inserts of large free-space ratios. In order that the pressure-drop data be extended to high air velocities, similar measurements were made for inserts sandwiched between glass cylinders 6 in. in diameter. In these tests, segmental baffles and downflow pipes were omitted, the pressure drop across three plates being measured, however, by means of the pressure-tap arrangement of the larger column. Data obtained in this manner agreed very closely with those for the 15-in. layout and

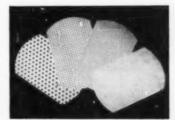


Fig. 5. One set of perforated inserts (11% free space).

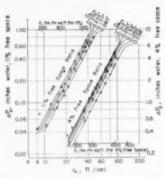


Fig. 6. Dry-plate pressure drop (4% and 11%

Note: "Free-space ratio" is defined as ratio total-area perforations to column-crosssection area.

so are included in the pressure-drop-vs.-

air-velocity curves for the dry plates. Runs with countercurrent flow of air and water were carried out by establishing a given water-flow rate as indicated by the rotameter and subsequently noting the pressure drop across the plate as the air velocity was increased and decreased at random. At low air rates, pressure drop was found to be practically independent of air velocity, and the plates were observed to be raining, i.e., water leaked back through the perforations, an indication of an unstable plate condition. For the small hole diameters this condition was characterized by inactive perforations with surface-tension effects preventing the raining. As the rate of flow of air was increased, bubbling through an increasing number of holes was observed until finally all holes were found to be bubbling uniformly and no water was dripping through the perforations. During this period, pressure drop across the plate was essentially constant or increased slightly with increase of air-flow rate, depending upon the amount of water raining through the insert. Rate of crease, however, was not uniform and frequently could not be reproduced because of the condition of instability previously re-ferred to. With all holes bubbling, pressure drop across the plate increased uniformly with increase in air-flow rate, the rate of increase of pressure drop depending on the insert used, the water-flow rate, and weir height, as discussed later.

Owing to the limited air supply available during these exploratory studies, the region of stable operation could not be reached on the plates of 17% free-space ratio. In fact, at high weir heights using 11% free space it was not possible in all cases to obtain measurements which extended very far into the region of stable operation. It is planned subsequently, however, to study inserts of subsequently, nowever, to study inserts of other perforation diameter and of higher free-space ratio by augmenting the air supply to the column. Tentatively, present data can be considered to give some idea of the magnitude of the pressure drop required for the gas- and liquid-flow rates encountered in a column of the type here described.

Discussion of Results

Performance of Dry Plates. In Figures 6 and 7 are plotted the total meas-

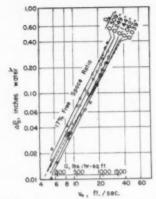


Fig. 7. Dry pressure drop (17% free space).

ured pressure drop across the dry plate as a function of the average linear air velocity through the perforations, with hole diameter as a parameter. For convenience, mass air velocities based on column cross section are also shown by means of the scale at the top of each plot. Linear air velocities shown were calculated by dividing the total volumetric flow of air (cu.ft./sec.) by the total area of all perforations on a given plate (sq.ft.). In the computation of mass air velocities through the empty column, an average air density of 0.077 lb./cu.ft. was used, corresponding to the generally prevailing temperature and pressure of the laboratory. Although the temperature, pressure, and humidity of the air entering and leaving the column were determined and recorded for each test, calculation showed that use of an average air density was well within the experimental accuracy for all runs reported.

For any given hole diameter and for triangular spacing, the data are seen to fall on straight lines with an average slope of 1.8 when plotted with logarithmic scales. With the exception of the two inserts having a square configuration, all data are for inserts with triangular spacing. Data for insert III-1 (0.039-in. hole diameter, 18.5% free space) having a square configuration fall on a straight line with a slope less than those for triangular arrangement, thus showing some effect of the layout of perforations on pressure drop at high free spaces.

It is of interest to note that for any air-flow rate and free-space ratio, pressure drop across a perforated plate increases with increasing hole diameter. The reason for this is not immediately clear, particularly when it is remembered that in the case of sharp-edged orifices there is a recovery of pressure loss as the ratio of orifice to pipe dia-

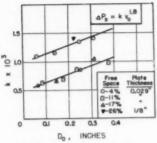


Fig. 8. Dry-plate drop correlation.

meter increases. In the present case, however, the ratio of total perforation area to column area (free space) is essentially constant so that the effect may be attributed either to the nature of the perforations themselves or to the manner in which the pressure taps were located. Since, in the present experiments, a knowledge of the total drop through the column was desired, no attempt was made to locate a vena contracta or to determine the variation in static pressure downstream from the plate surface. On the other hand, for any gas velocity and perforation diameter, pressure drop, as would be expected, is found to decrease as freespace ratio increases.

Data for the dry trays can be correlated if it is assumed that a simplified form of the orifice equation applies. Thus, orifice coefficients can be calculated from the equation

$$v_a = C(2g\Delta H)^{\frac{1}{2}} \tag{1}$$

where vo is the average linear air velocity through the perforations, ft./sec., and ΔH is the pressure drop across the plate, ft. of fluid flowing. Coefficients computed in this manner are shown plotted in Figure 9 as a function of air velocity through the perforations, with perforation diameter and free-space ratio as parameters. Attempts to correlate values of C with a modified Reynolds number based on a suitable equivalent diameter were not successful. Values of C for these plates vary from about 0.55 to 0.85 and increase with decreasing hole size and with increasing free space. The curve for insert III-1, having a square hole spacing and high free-space ratio, differs considerably from curves of triangular spacing, as might be expected from inspection of the curve on Figure 7. It is believed this behavior is probably a result of the closer spacing of holes in this insert compared with insert I-1.

Use of Equation (1), however, involves coefficients which vary with vapor velocity. Inspection of Figures 6 and 7 shows that the experimental data

can better be represented by an equation of the form

$$\Delta P_D = k v_a^{-1.8} \qquad (2)$$

where ΔP_D is the pressure drop across a dry plate, in. of water, and k is an empirical, dimensional coefficient. Values of k computed according to this equation are essentially independent of flow rate in the range investigated and can be plotted against perforation diameter with free space as a parameter, as shown in Figure 8. Unfortunately, results for free-space ratios lying between 4 and 11% are not available, and so interpolation between the curves shown is uncertain.

The solid data point indicated was calculated from data reported by Lerner and Grove (11), who measured the pressure drop across a perforated plate containing holes 0.219-in. diam. and having a free-space ratio of 26% (based on plate layout of the 15-in, column). Failure to agree with the present results may be tentatively accounted for by the fact that a relatively thick plate (1/8 in.) was employed as compared with the thin plates (0.029 in.) used in these studies. Despite the oversimplification of the treatment employed here, use of Figure 8 may serve as a first approximation for estimation of dry-plate pressure drop for plate layouts of the type investigated.

Performance of Plates with Counterflow of Water. The performance of a perforated plate with countercurrent flow or air and water is most readily shown by reference to the curves of Figure 10. Here pressure drop across the operating plate is plotted as a function of air mass velocity (based on empty-column cross section) with mass velocities of water as parameter. Data for zero water-flow rate (dry plate) are shown for comparison.

For air-flow rates less than those indicated by points designated A on the diagram, water drains freely through the



Fig. 11. Perforated plate in region of stable operation.

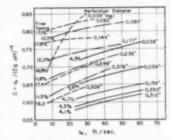


Fig. 9. Dry-plate orifice coefficients.

Fig. 10. Determination of limiting points of column operation, insert 1-4, 0.250-in. holes, 4.5% free space, ½-in. weir.

holes adjacent to the inflow weir, and there is no bubbling on the plate. In the region A to B some perforations become operative, the number increasing steadily until all holes are bubbling at point B. Above this point stable plate operation prevails, and contacting between gas and liquid is good. Visual observation during test lends emphasis to the statement previously made that a perforated-plate column should be designed for operation in the region above point B. While a column may be expected to provide some degree of contacting in the region slightly below B, it is doubtful that optimum plate efficiency will result because of the poor bubbling action on the plate. Further studies

Free space Perforation Weigh

during actual distillation operation are necessary, however, before this effect is established quantitatively.

Figure 11 illustrates a perforated plate in the region of stable operation.

Results for five inserts are given in Figures 12 to 23. In addition to show-ing the effect of varying water and air velocities, these curves show also the effect of static liquid seal, or weir height. Points at which incipient plate stability occurs, as visually observed, are noted by heavy arrows. These points to not in all cases agree exactly with those found graphically, since the former were conservatively determined only when it was seen that all perforations had ceased

TABLE 3 .- MINIMUM AIR-MASS VELOCITIES FOR STABLE OPERATION

	Free space,	Perforation	Weir			
Insert		diameter, in.	height, in.	L	Gmin.	$(v_e)_{min}$
1-2	3.9	0.059	36	270	415 graphical	39
			100	900	410 graphical	38
			17	2700	470 graphical	44
			1/2 1/2 1 1	270	430 graphical	40
				900		39
					420 graphical	
			1 2	2700	435 graphical	40
		1	26	270	435 graphical	40
			2	900	430 graphical	40
			2	2700	440 graphical	41
8-4	4.5	0.250	86	270	390 graphical	31
			10	900	390 graphical	31
			16	2700	410 graphical	3.3
			1	270	470 graphical	38
			1	900	470 graphical	3.8
			1	2700	470 graphical	3.6
				270	500 graphical	40
			· ·	900	500 graphical	40
			2 2	2700	500 graphical	40
1-5	4.1	0.312	1/	270	200 mechinel	34
1.0	W- A	0.012	79		390 graphical	
			1 1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2	900	390 graphical	24
			19	2700	420 graphical	87
			1	270	430 graphical	2.6
			3	900	440 graphical	39
			1	2700	440 graphical	29
			2	270	460 graphical	41.
			2	900	470 graphical	4.1
			2	2700	440 graphical	39
II-1	10.5	0.083	1	270	790 visual	27
			1	900	810 visual	26
			1	2300	870 visual	30
			9	2700	890 visual	21
				270	850 visual	29
			9	900	83) visual	29
			9	2300	850 visual	29
			-	2700	850 visual	29
			4	2700	832 visual	28
			4	2300	850 visual	29
			29	270	720 graphical	2.5
			79	900	800 graphical	28
			29	2360	630 visual	29
			76	2700	900 visual	31
11-4	11.5	0.373	1/4 1/4 1 1 2	270	750 graphical	24
			3/6	900	800 graphical	2.5
			1	2700	900 graphical	28
			1	2300	900 graphical	26
			2	270	800 visual	25

TABLE 4.—COMPARISON OF PREDICTED PRESSURE DROP WITH DATA OF HUTCHINSON, ET AL. (6)

 Perforation diameter: % in.
 8.6%

 Free-space ratio (based on N.C.S. 15-in. column layout)
 8.6%

 Free-space ratio (based on perforated sone only)
 14.5%

 Liquid-flow rate.
 1600 lb./(hr.)(sq.ft.)

$B_{avg.}$, in.	G lb./(hr.)(sq.ft.)	ΔP _{prod.} , in. water	ΔP _{obs.} , in, water	Deviation from ΔP_{pred} , %
0.97	800	1.89	1.25	+10
	900	1.86	1.60	+14
	1800	8.06	3.60	+15
2.47	800	2.63	2.32	+ 12
	900	3.02	2.60	+ 14
	1800	4.04	3.45	+ 15

to drain and all were bubbling steadily. Because of the excessive air requirements for inserts of high free-space ratio, there is some uncertainty in the location of points of incipient plate stability for these tests. Furthermore, inability to attain air-mass velocities above 900 lb./(hr.)(sq.it.) poses an additional limitation. It is planned subsequently to extend these data to still higher air and water flows while employing the same column and inserts.

Minimum Velocities. Minimum air velocities for stable plate operation are summarized in Table 3. Although some values were determined graphically, these show that minimum allowable air velocities are essentially independent of water rate and perforation diameter but are dependent on column-liquid holdup (weir height). As might be expected, also, higher minimum gas-mass velocifies through the column are required for Stable plate performance as free space increases. It is of interest to note that these values of G correspond to higher superficial vapor velocities through the column but to lower linear velocities through the perforations, vo, at the higher free-space ratios (see Table 5). Several experiments were carried out to determine possible effects, if any, on performance due to hydraulic gradient and column holdup. Because of the small diameter of the column used in these studies, hydraulic gradient was negligible, while, over the range of air and

water flows used, measured values of column holdup were found to vary essentially with weir height. Data on larger columns and for greater gas and liquid loads are needed to determine the effects of these factors on performance.

Aeration. Aeration factors were calculated according to the definition proposed by Kemp and Pyle (9) for several inserts operating in the stable region. This was done by dividing the increase in pressure drop corresponding to two different weir heights by the difference between the weir heights. This assumes, of course, that the weir height is equal to the clear liquid static seal, an assumption which appears to be justified for the present plate construction, which incorporated a suitable splash baffle. It is doubtful whether a clear liquid seal equivalent to the weir height can be achieved without use of such a baffle (or other calming device), as pointed out by previous investigators (3, 6, 9, 14, 17). Although aeration factors were generally much less than unity and decreased with increasing air rate, it is not yet clear how they can be utilized in prediction of pressure drop across sieve trays. For this reason, aeration factors are not reproduced here.

Liquid Seal. Several experiments were carried out in an attempt to determine a so-called equivalent clear liquid seal by inserting a pressure tap at one of the perforations near the center of

the plate. A copper tube was inserted from below the plate through the hole and then flared slightly so that the open end was flush with the top surface of the plate. This tube was then connected to a water manometer so that the pressure at this point on the plate might be read as a head of clear, unaerated liquid outside the column. Perforations surrounding this pressure tap were not blanked off since it was desired to include in the measurements any effect of bubbling or aeration of the liquid. Although manometer readings fluctuated owing to turbulence on the plate, average readings could be ascertained.

The equivalent clear liquid head when subtracted from the over-all pressure drop across the plate over the range of air-mass velocities prevailing in the stable region results in the curve shown in Figure 24. The solid line represents the pressure drop for the dry plate alone. From this plot it is clear that the total pressure drop across a plate is not simply the sum of the dry-plate pressure drop and a clear liquid head or seal corresponding to the depth of aerated liquid on the tray. Inspection of the data shows that an amount equal to approximately 10% of the dry-plate pressure drop is not thus accounted for. That complete agreement between the two curves should not be expected is partially explained by recalling that some pressure is lost by bubble formation as air issues from the perforations and by turbulence and mixing of the air-water mixture flowing across the plate. Consideration of these factors further emphasizes the complexity of the phenomena occurring on sieve trays.

Liquid-flow Pattern. To study the liquid-flow pattern in the bubbling zone of the plate, a long glass tube was inserted from the top of the column through one of the perforations of the top plate to discharge an ink stream on the middle plate. These observations were made on insert II-4 for values of

TABLE 5 .- VAPOR VELOCITIES FOR VARIOUS PERFORATED PLATE COLUMNS

	Column diameter I.D., in.	Perforation Diameter, P_o , in.	Hole-diameter- to-spacing ratio	Free- space ratio, %	Vapor (gas) velocity thru holes, v _o , ft./sec.	Superficial vapor velocity thru column, u, ft./sec.	Reference	
8.	10	0.063	80,0	0.2	> 40	> 0.16	N. C. State, 10 in.	
3.	4.3	0.125	0.11	1.1 1.9	53-145 36-122	0.59_1.6 0.68_2.33	Bagnoli (1) Pigford and Colburn (18) (Volland)	
4.	13	0.125	0.17	2.5	63_110	1.7 - 2.84	Bagnoli (1)	
5.	4.8	0.079	0.20	3.6	25_51	0.9 -1.8	Kirschbaum and Andrews	(10)
6	15	0.312	0.28	4.1	> 35-45	> 2.5 _8.2	N. C. State (1-5):	
7.	15	0.059	0.27	3.9	> 37-41	> 2.7 _3.0	N. C. State (I-2):	
8	15.7	0.079	0.29	7.4	9_28	0.74-2.1	Pigford and Colburn (18) (Kirschbaum)	
9.	4.3	0.079	0.29	7.4	5_38	0.38-2.8	Pigford and Colburn (15) (Kirschbaum)	
10.	15	0.250	0.29	4.5	35_45	2.6-3.4	N. C. State (I-4)?	
11.		0.047	0.30	3.4	12-40	0.4-1.4	Kamei and Umeshita (7)	
12.	4.3	0.098	0.36	11.3	2.6_18	0.3-2.0	Kirschbaum and Andrews	(10)
13.	24×48	0.125	0.40	8.6°	20-25	2.9-3.6	Hutchinson et al. (6)	
14.	66	0.500	0.45	14.5	> 16_18	> 2.9-3.2†	Gunness and Baker (8)	
15.	15	0.083	0.44	10.5	> 24-28	> 4.3-5.0	N. C. State (II-1)?	
16.	1.5	0.376	0.46	11.5	> 24	> 4.6	N. C. State (II-4):	

Based on bubbling sone to column area of N. C. State 15-in, column, "Plates probably leaking" (Ids). Vapor-velocity values for N. C. State columns are minima for stable plate operation.

air-mass-flow rate, G = 570 to 970, and liquid-flow rates, L = 270 and L = 2300.

It was noted that when dye was discharged on the frothing surface (top of the bubble layer), the color was very rapidly dispersed in all directions. When the ink was released on the surface of the insert between the bubbling perforations, a vertical movement of the liquid was indicated with essentially no horizontal flow on the plate surface.

Dye placed at the junction of the frothing surface and the splash baffle was washed downward over the face of the baffle to the surface of the plate, where the stream divided. One part of the stream traveled under the baffle and over the downflow weir to the plate below, while the other part flowed back to the bubbling zone of the insert. A considerable downflow liquid stream was similarly identified at the column walls and even at the inflow weir. Attempts to determine the existence of downflow streams within the bubbling zone were unsuccessful, owing to the rapid dispersion of the dye and to poor visibility in the areas remote from the glass walls and below the bubbling surface.

From these observations it might be concluded that the liquid flow is essentially a multitude of vortices with the major downflow areas occurring at the periphery of the bubbling zone, i.e., the column walls, the splash baffle, and the inflow weir. It appeared that the local horizontal-velocity component of liquid flow across the plate was very small compared to the vertical pattern described above.

Entrainment. While no entrainment measurements were attempted, general observations of liquid splash-up were made for each run, and instances of high entrainment were recorded. Although there was at all times a very fine mist carried upward from the plate (as much as 8 to 10 ft. above the top plate at high air velocities), it appeared that the actual amount of liquid transported as entrainment from plate to plate was very

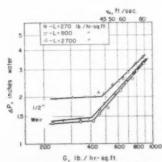


Fig. 12. Pressure drop, insert 1-2, 0.059-in. holes, 3.9% free space.

small in most runs. The entrainment tendency increased somewhat with increasing perforation diameter, and in cases of higher air-flow rates at low liquid-flow rates in conjunction with the low weir height it became excessively great. The conclusion that this high entrainment was a result of insufficient liquid holdup on the plate to maintain a dispersion of the air as bubbles in the water, was supported by column-holdup measurements and by high-speed photographs of the bubbling zone. From these observations, it is suggested that liquid entrainment may be reduced at the lower liquid-flow rates (low L/G reflux ratios) by the use of higher downflow weirs.

Application of the entrainment studies of Kamei, Takamatsu, and Umeshita (7) to the interpretation of observations of this investigation are hampered by the problem of determining a satisfactory liquid-seal value for that work. It is believed that installation of a splash baffle may have changed the finding that "the volume of overflow and the height of the weir did not influence [to] the driving force of entrainment directly."

Surface-tension Effects. As a qualitative consideration of surface-tension effects, a frothing agent such as is used in froth flotation cells was added to the entering water stream. Instead of the anticipated increase in the height of the foam layer and frothing surface, there were produced a lower frothing surface, a reduction in the amount of entrainment, and a more stable plate in general. A significant factor in establishing these conditions lay, no doubt, in the much smaller air bubbles constituting the foam layer or frothing surface after the addition of the frothing agent. The same result was achieved by the addition of a sudsing household detergent to the water stream.

Effect of Fluid Properties. In view of the fact that a single system, airwater, was employed in this investigation, the effect on plate operation of fluid properties was not experimentally evaluated. It is for this reason that air

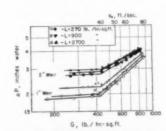


Fig. 13. Pressure drop, insert 1-2, 0.059-in. holes, 3.9% free space.

rates are presented only in terms of average linear air velocity through the perforations, vo. or of air-mass velocity through the column, G. By analogy to treatment for bubble-cap columns, effects due to gas density can tentatively be accounted for by use of the so-called F factor $(F = u(\rho_v)^{1/2})$, where u is the average linear vapor velocity through the column and ρ_v is the vapor density). An alternative procedure is to use the term G/ϕ where $\phi = (\rho_v/\rho')^{\frac{1}{2}}$, where o' is the density corresponding to some arbitrarily chosen conditions of temperature and pressure. For present data, ¢ can be taken nearly equal to 1.0 if p is taken as 0.077 lb./cu.ft. since actual air densities in the column were close to this mean value. It is interesting to note that minimum allowable air-mass velocities (Table 3) of 400 to 900 lb./ (hr.) (sq.ft.) correspond to F factors of 0.4 and 0.9, respectively.

Comparison with Bubble-cap Plates. Comparison of the performance of the perforated plate with that of the bubblecap plate is, in view of the many variables involved, difficult and must be made with care. Pigford and Colburn (15) indicate an operating range of F factor of 0.05 to 1.1 for bubble-cap plate columns. The minimum vapor loads of perforated plates of F factor 0.4 for the 4% free-space ratio and 0.9 for the 11% free space indicated by this investigation suggest that the perforated plate in stable operation carries a vapor load equal to and in some cases greater than that reported for corresponding bubblecap plates. Nelson (13) suggests superficial tower velocities of 0.4 to 3 ft./sec. for refinery operation. Table 5 indicates unstable operation of perforated plate columns with the higher free-space ratios at superficial vapor velocities less than 3 to 4 ft./sec.

In the limited range of air-flow rates for which data have been obtained in this work, reflux ratios up to L/G values of about 7 with stable plate operation have been achieved easily to suggest a

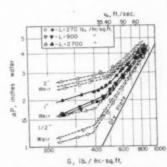


Fig. 14. Pressure drop, insert 1-4, 0.250-in. holes, 4.5% free space.

potential application of the perforated plate to extractive distillation.

As a comparison of the order of magnitude of the pressure drop across the plates, Table 6 presents a few observed pressure-drop data for the various perforated inserts with corresponding values reported by Peavy and Baker (14) for a bubble-cap plate column.

Prediction of Pressure Drop. In the design of perforated-plate columns for distillation or absorption operations, it may frequently be desired to predict empirically the pressure drop across the trays under various operating conditions. Analysis of the data for both dry and wet plates suggests a method for estimating the pressure drop across plates similar to the type studied.

If in the region of stable operation the static liquid seal or weir height is added to the pressure drop for the dry plate, the resulting value is seen to approach that for the operating plate at the same air-mass velocity. If the effect of liquid-flow rate is sufficiently small to be negligible, the total pressure drop can be predicted approximately by an equation of the form

$$\Delta P = R(\Delta P_D + S) \tag{3}$$

where ΔP is the predicted pressure drop, ΔP_D that for the dry plate, S the static liquid seal, and R an empirical correction factor. Over the range of air- and water-flow rates studied, the factor R is found to be dependent primarily on the static seal, decreasing as weir height increases. For the present data, values of R were calculated according to Equation (3) and are shown plotted in Figure 25. Use of this correction factor curve permits estimation of pressure drop within about 5% for values of L around 1000 lb./(hr.)(sq.ft.). range of air and water rates covered is not sufficiently great to justify at this time further refinement by inclusion of this additional variable.

Hutchinson, Buron and Miller (6) reported pressure-drop data for a stam-

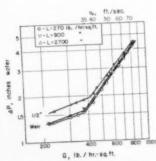


Fig. 15. Pressure drop, insert 1-5, 0.312-in. holes, 4.1% free space.

TABLE 6.- PRESSURE PROP COMPARISON WITH DATA OF PEAVY AND BAKER (14)

$$G = 720 \text{ lb./(hr.)(sq.ft.)}$$

 $L = 700 \text{ lb./(hr.)(sq.ft.)}$

		4	P, in. water	
Plate description	Free-space ratio, %	S = 1/2 in.	S=1 in.	g=2 in.
A For sup	erficial vapor ve	elocity = 3 ft./s	ec.	
Peavy and Baker N.C.S. 1-2 N.C.S. 1-4 N.C.S. 1-5 N.C.S. II-1 N.C.S. III-1	9.4 8.9 4.5 4.1 10.5	1.6 2.3 3.1 3.6 1.2 1.0	1.9 3.1 3.5 3.8 1.5	2.3 3.7 4.0 4.3 2.2 1.8
	G = 900 lb./(L = 900 lb./(hr.) (sq.ft.) hr.) (sq.ft.)		
Peary and Baker N.C.8. 1-2 N.C.8. 1-4 N.C.8. 1-5 N.C.8. 11-1 N.C.8. 11-1	9.4 3.9 4.5 4.1 10.5	1.9 3.5 4.2 4.9 1.25	2.4 3.8 4.5 5.0 1.85 1.35	2.6 4.2 4.8 5.4 2.2 1.9

less-steel sieve plate with ½-in. perforations on $\frac{5}{16}$ -in. equilateral triangles. The method of prediction applied to several sets of their data gave results as shown in Table 4. Predicted pressure drops are roughly 10 to 15% higher than observed yet possess the advantage of being on the conservative side.

Ultimately any satisfactory method for prediction of perforated-plate behavior must also take into account such important factors as hydraulic gradient, aeration of the liquid, holdup, foaming, entrainment and probably others. Again, many additional data and further analysis of plate behavior are necessary before the interrelationships of such factors can be brought into proper perspective.

Acknowledgment

The authors gratefully acknowledge partial support of this study through a Frederick Gardner Cottrell grant-in-aid made by Research Corp., New York, N. Y. The assistance of Willard Till in construction and erection of equipment is sincerely appreciated.

Notation

C = orifice coefficient.

$$\frac{v_0}{(2g\Delta H)^{\frac{1}{2a}}}$$

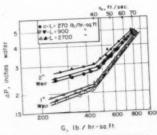


Fig. 16. Pressure drap, insert 1-5, 0.312-in. holes, 4.1% free space.

 $D_a = \text{diameter of perforation, in.}$ $F \text{ factor} = u(\rho_v) \frac{v_0}{2}$

Free-

space ratio = ratio of total perforation area per plate to emptycolumn cross - sectional area, analogous to the ratio of total slot area to column cross section for bubble-cap trays. The free-space ratios listed are all based on the plate design of the 15-in. column in which the area of the perforated insert is 59% of the column cross-section area

g = gravitational constant, ft./
sec.²

G = gas-mass-flow rate, lb./
(hr.)(sq.ft.), based on
column cross-sectional
area (for 15-in. N.C.S.
column plate layout)

ΔH = pressure drop across dry plate, ft. of fluid (gas or vapor) flowing through the plate

k = empirical, dimensional co-

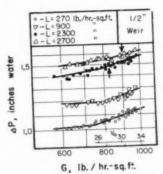


Fig. 17. Pressure drap, insert 11-1, 0.083-in. holes, 10.5% free space.

efficient for dry-plate APD pressure drop-

L = liquid-mass-flow rate, 1b./(hr.) (sq.ft.), based on column cross - sectional area (for 15-in. N.C.S. column plate layout)

 ΔP = pressure drop across one plate of a plate column, in, water

 $\Delta P_D = \text{pressure drop across dry}$ plate, in. water

0-L=270 lb./hr-sq.ft.

₽-L=900

-L=2300

△-L=2700

2.0

water

AP,

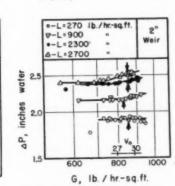
1.5

1.0

R = pressure - drop correction factor for perforated

Weir

1000



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Fig. 19. Pressure drop, insert II-1, 0.083-in. holes, 10.5% free space.

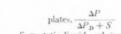


Fig. 18. Pressure drop, insert II-1, O.083-in. holes, 10.5% free space.

600

S =static liquid seal (equal to weir height for columns with negligible hydraulic gradient and suitable splash baffle), in.

800

G, Ib. / hr.-sq.ft.

н = superficial gas (or vapor) velocity through column, ft./sec.

vo = average linear gas (or vapor) velocity through individual perforations, ft./sec.

 $\rho_c = \text{density of gas or vapor,}$ lb./cu.ft.

 $\rho' = density of standard gas,$ lb./cu.ft.

d = vapor density correction factor.

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Discussion

F. M. Thayer (du Pont Co., Victoria, Tex.): What effect on plate efficiency might be expected from the slope of a perforated plate that is not mounted level?

D. S. Arnold: For column operation below the minimum vapor velocity for stable plate performance (as defined here), the vapor would pass through the perforations of the high side of the plate

while clear liquid would collect on the low side and probably drain through the perforations. However, if the perforations are small enough, surface tension effects would prevent this drainage.

For column operation appreciably above the minimum vapor velocity, the effect of the inclination of the plate would be one of increasing the liquid seal on the lower part of the plate. For a given vapor velocity through the perforations, this would produce a higher pressure drop across the low side of the plate; consequently, it is expected that the vapor would pass through the low side as well as the high side but at a

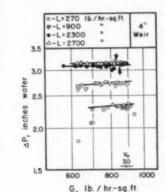


Fig. 20. Pressure drop, insert II-1, 0.083-in. holes, 10.5% free space.

lower velocity to compensate for the greater liquid seal; moreover, it is anticipated that there would be vaporliquid contacting over the entire plate with only a slight loss in efficiency.

B. G. Price (Celanese Corp., Clarkwood, Tex.): Was the lower limit of the zone of stable operation approached from both the stable and unstable regions and, if so, was there any indication that the so-called weeping point varied with the direction of approach? Was there evidence of a correlation between the k used in the empirical evaluation of pressure drop across a dry plate and the coefficient normally associated with an orifice of the same diameter?

D. S. Arnold: Yes, the limiting velocity for stable operation was approached from both directions and no variation was observed. No attempt was made to relate the empirical factor k to standard orifice coefficients.

H. E. O'Connell (Ethyl Corp., P. O. Box 341, Baton Rouge, La.): What was the significance of the fact that you obtained different correlations for the three free spaces studied?

D. S. Arnold: We believe that the difference is probably due to the fluid flow pattern, in the neighborhood of the

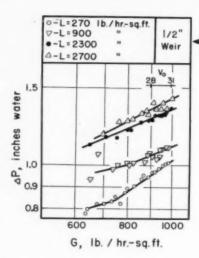


Fig. 21. Pressure drop, insert 11-4, 0.376-in. holes, 11.5% free space.

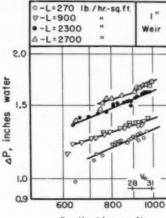


Fig. 22. Pressure drop, insert 11-4, ► 0.376-in. holes, 11.5% free space.

G. Ib. / hr.-sq.ft.

perforations. In other words, the distance between individual perforations is significant and as the perforation separation decreases, there is apparently an interaction between the streams flowing through the two perforations on either side the downflow or upflow side. That is our interpretation of it. We have no quantitative considerations.

Anonymous: You stated that there was an "entrance effect" which you noticed across your bottom plate. Would you care to say how much that effect is and whether it is due to the entrance into the section below or to something different about the bottom plate itself?

D. S. Arnold: Observations before and after exchange of plates to different positions in the column demonstrated that pressure drop across the different plates was reproducible from plate to plate. Consequently, it was concluded

that the "entrance effect" was produced by the air flow pattern in the section of the column below the bottom plate rather than by any plate irregularity. This entrance effect appeared as a deviation in pressure drop across the bottom plate up to 10% from that of the plates in the other two positions in the column.

Cecil E. Turnquist (Monsanto Chemical Co., St. Louis, Mo.): You stated that the pressure drop observed was proportional to the 1.8 power of the mass velocity instead of the anticipated 2.0 power of the mass velocity. I believe this is normal behavior for turbulent flow. In addition, for turbulent flow conditions, the friction factor in the pressure-drop formula is proportional to the -0.2 power of the mass velocity. This factor accounts for the difference between the anticipated and the observed relationship between mass velocity and pressure drop.

D. S. Arnold: We didn't elaborate on that difference.

Anonymous: What is the range of operability depending upon your visual observation of the maximum flow rate possible?

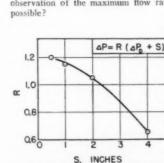
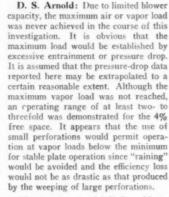


Fig. 25. Pressure-drop correction factors.



(Presented at A.I.Ch.E. Atlanta (Ga.) Meeting.)

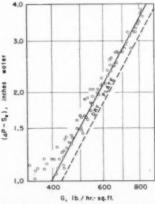


Fig. 24. Total pressure drap minus equivalent clear liquid seal, insert 1-5.

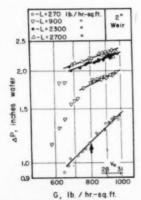


Fig. 23. Pressure drop, insert II-4, 0.376-in holes, 11.5% free space.

The Engineering Approach to SALES

ORE and more chemical companies are adopting what may be called the "engineering approach to sales." Marketing is becoming increasingly a matter of technical competition. Quite aside from the technical characteristics of the chemical product, science is playing an important part in the strategy of marketing. Of course, the science of market research is different from the science of engineering even though it has used generously some fundamental engineering techniques.

Most persons think of chemical market research in connection with new products. However, many companies are today using market research to guide sales, advertising, research, manufacturing, purchasing, and other management functions as they relate to the old-line products. More and more, the talents of the market research department as a fact-finding agency are being put to work. This is particularly true where the department maintains its status as an unbiased source of facts. The market research department should refrain from becoming an advocate of a given course of action. This decision is best left to the departmental policy makers.

Market surveys are particularly useful to the sales manager for the oldline product. In the case of the new product, the status of general business is but a small factor in the marketing problem. A unique and useful product will sell in the severest depression, but a product which has achieved maturity may be greatly susceptible to the variable winds in the economic weather. Market research is an invaluable tool for charting a proper course through troubled times. Therefore, in a highly competitive industry the sales manager with the best fact-finding machinery is likely to be the sales manager with the most business, and the chemical industry is becoming increasingly competitive. The time at which it is most important to make the right decisions, consequently, is at turning points in the economy.

During the period when business is continually good, a sales manager and salesman alike can make many errors that will not have too great a bearing on the long-term trend of their business; the same is true when business is poor. But if mistakes are made at the turning points of business, those are the mistakes that can seldom be rectified and that result in a long-term loss of business or prestige. Turning points are the times at which business turns good or bad. The man who finds it possible to predict these turning points can easily maneuver himself into a position of supremacy over his competitors. By way of illustration, two examples can be given. For example A, suppose a chemical has been in short supply for a long period of time. Usually the seller allocates this chemical to his old customers on a fairly routine basis, seeing that all obtain their fair share. If, however, he can successfully predict that two months hence the supply will become adequate and in fact may well be surplus, he can then make additional sales for delivery two months hence, knowing that some of his regular customers will not demand as much as their current orders. If the sales manager correctly calls this turn of business, he may continue to operate his plants at capacity during the ensuing period of slack business; whereas his competitors who were not so foresighted are selling much less than their capacity and therefore have to cut back production.

Example B is the kind of situation that develops when the turning point is upward. During a period of slow business the sales manager is naturally trying to obtain all the orders he possibly can. If, however, he can predict that three months hence business on this commodity will sharply increase, then he can concentrate his sales effort on those areas where the business is more profitable and on those grades of product on which the greatest profit can be made. Also, he can stimulate his plant to additional production in order to build up a large inventory for sale at a time when the market becomes good. Thus, he gains in two ways. He obtains the high dollar for all he is able to produce, and also he sells more than normal because of the accumulated inventory (assuming a capacity limitation).

It is fairly obvious that the sales manager who can guess both these situations and act properly both times is indeed a rare individual. However, there is no question but that his ability to come closer to the right answer is greatly en-



M. E. Clark

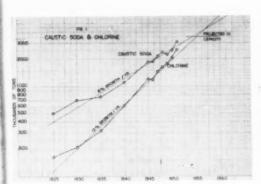
Melvin E. Clark received a bachelor's degree in chemical engineering from the University of Colorado. After four years with Chemical Engineering, Mr. Clark joined Michigan Alkali Company in 1941 as director of market research but left to work with the War Production Board, where he was chief of the planning and program branch of the chemicals division. After two years as director of market research for Wyandotte Chemicals Corporation, Mr. Clark became manager of heavy alkali sales for the company in 1946, and in 1952 advanced to be general products manager of the Michigan alkali division.

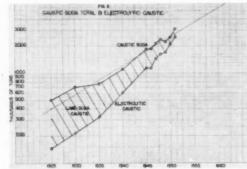
hanced by facts gathered from accurate market research. Perhaps the best way to show the importance of the market survey in determining policy relative to old-line products is to describe an actual problem, its analysis and possible solutions. This case history, meant to serve only as an example, is based on chemical market research data. The problem chosen for this discussion is one that has been widely heralded in chemical publications for ten years. It is the relationship between chlorine and caustic soda as basic chemicals of commerce of the alkali industry.

Chlorine has sometimes been called the Cinderella chemical of the alkali industry because of its tremendous growth curve. Over the period of the past 25 or 30 years, chlorine has found new markets so fast that its production has increased by an average rate of 12% per ine is made by this method. Caustic soda, on the other hand, is made by two methods. In addition to the electrolytic process, it is made by the older process of the chemical reaction of soda ash and lime. Prior to 1939, the tonnage made by the chemical method was greater than the tonnage made by the electrolytic method (see Fig. 2). However, because of the great strides in chlorine since that year, electrolytic production is now predominant. In fact, about 80% of all caustic soda is made from the electrolytic process.

Ever since 1940 it has been predicted by some that the next chlorine expansion would spell disaster for the caustic soda industry because more caustic would be produced than could be absorbed by the market. If as a result chemical caustic should be withdrawn from the market, a problem would arise, because trends, and the effects of price change. Let us first take a look at the market for chloring

Broadly speaking, chlorine has three major markets (see Fig. 3): as a chemical raw material for other chemicals, as a bleaching and solubilizing agent for wood pulp, and as a sanitizing agent for water and sewage treatment. The first-named market takes so much of the chlorine that it is desirable to break down this figure into smaller units. The principal items involved are chlorinated solvents used for cleaning and degreasing purposes, ethylene glycol used as an automotive antifreeze, vinyl chloride used as a base for plastics, chlorinated hydrocarbons for insecticides, and sodium hypochlorite for bleach. These five types of chemicals take the major portion of chlorine going into the chemical industry. There are





year (see Fig. 1). (This compares with population growth of slightly over 1% per year.) Actually, chlorine is relatively new as a bulk chemical. It is really a product of the twentieth century. However, it has already passed the 2,000,000-tons-per-year mark in volume of production.

Caustic soda, on the other hand, is a product as old as the ancient Egyptian soapmakers. It has, of course, found many new markets in recent years and has grown fast in the old ones. Because the novelty of this item has worn off, however, it is not growing at the tremendous rate that chlorine grows. As a matter of fact, the 25-to-30-year growth trend for caustic soda shows a rate of about 6% per year (see Fig. 1).

Most of the chlorine made in the United States is made as a coproduct with caustic soda by the electrolysis of salt brine. In fact, over 90% of chlorchlorine and caustic soda would be produced in molecular equivalent amounts. It would be like having a team of horses hitched to a wagon, in which one horse was twice as fast as the other. Obviously, the progress of the wagon would be determined by the slower of the two horses. In this case the progress of the production of these two chemicals would be determined by the sales for caustic, for which uses are developing at only half the rate as for chlorine.

Thus, we have the problem. It is fairly obvious that there would be a strong market for chlorine. It is to be expected, however, that the possibility of a long market on caustic soda would deter some manufacturers from expanding chlorine production as much as their customers would desire. Obviously, some market research facts are needed which will indicate the character of the markets involved, the probable future

also other big uses such as tetraethyl lead for motor fuel, synthetic phenol for plastics and medicinals, etc.

It is readily apparent to even the casual observer that in almost all of these uses of chlorine, growth is continuing. It is, therefore, logical to expect more chlorine to be needed in the future than in the present. At the same time, many of these uses do not have an inexhaustible market, particularly in regard to price. For example, in the manufacture of ethylene glycol, chlorine is not absolutely essential. There are other methods of making ethylene glycol in commercial operation today which do not involve the use of chlorine. Increased prices of chlorine would tend to stimulate production by the nonchlorine methods of manufacture. The same is true of metal degreasing. There are other ways to clean metal parts which do not involve the use of chlorinated solvents. If the price of these solvents goes too high, it may well encourage the use of the other methods. Pranol can be made by processes that do not involve chlorine, and it is quite possible that higher chlorine prices would tend to shift the production of this item to these other processes. The purpose of these illustrations is to point out that the total market for chlorine, just as for most commodities, is definitely a function of the price at which chlorine is sold.

Similarly, it is logical to expect that the price-demand relationship will affect caustic soda. Caustic soda also finds its largest outlet in the chemical industry (see Fig. 4). However, the second largest outlet is the rayon industry, which consumes a tremendous tonnage each year. Other large markets are in the soap industry, in pulp and paper, in petroleum refining, and in textiles. These are all growing markets, but inasmuch as their technology has been well developed over a long period of years. there is not the possibility of so rapid an increase in the rate of usage as is true in the case of chlorine. The best opportunity for caustic soda growth is in industries where chlorine is also used, and there is a desire on the part of the consumer to create a larger caustic soda market in order to assure himself of adequate supplies of chlorine. The outstanding industry in this respect is the pulp and paper industry.

Chlorine is used largely for bleaching in the pulp industry, and many of the pulp plants do this bleaching with a calcium hypochlorite solution. They have known for some years that a sodium hypochlorite solution will bleach just as well, in fact will show some advantages. However, in years past, the large differential between the cost of caustic and that of lime has made the calcium hypochlorite process more attractive. Now, when these economics are reevaluated with certain new data which have been brought to light, including (1) the saving in chlorine used, (2) reduced stream pollution, (3) improved rate of production. (4) improved quality of product, (5) easier handling of raw materials, and (6) resultant greater availability of chlorine, the sodium hypochlorite method takes on new significance. The use of caustic soda is expanding tremendously in this market and will no doubt grow quickly in the next two or three years. Also, there exists the possibility of greatly expanding the export market for caustic soda. In 1951 the United States took a much larger share of the world market than heretofore. The world market is a growing market, and with a United States policy that tends to stimulate world trade, there is little doubt that we can

expect to share more importantly in the world market for this item than in years past.

Caustic soda would also show a change in market potential based on price change. The market would probably shrink with higher prices and increase with lower prices. There is not sufficient time here to discuss this economic ratio, but it is the writer's conclusion that a very substantial price reduction would have to occur to offer an appreciable increase in market potential.

These are two factors affecting the

market picture—consuming industries and price-potential relationship. A third factor is plant location. Chlorine plants are well scattered over the eastern part of the United States. In years past they were located over available supplies of pure salt or low-cost power (see Fig. 5), but more recently expansions are being built nearer large consuming areas (see Fig. 6). Because of the importance of freight in the delivered cost of these items, it will be possible in future years to have shortages in one area and surpluses in another, just as

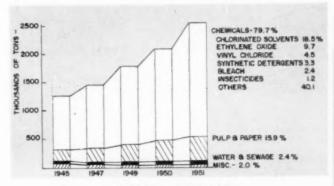


Fig. 3. Chlorine consumption by industry.

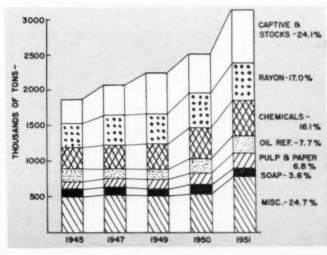


Fig. 4. Coustic sede consumption by industry.

has been the case with sulfuric acid. Caustic soda plants are at the same locations as chlorine plants in most cases.

What is being done about new chlorine production might well be the next question. Last year's capacity in the United States was about 6,700 tons per day. It is currently being expanded to about 9,700 tons per day, this program to be completed by the end of 1953. The new plants are located as

shown in Fig. 6. This 3,000-ton-per-day expansion program, however, is being accompanied by a minimum expansion of caustic soda of only 1,600 tons. The reason is that some plants are being built without finishing capacity for caustic soda, and in other cases the new electrolytic caustic is designed to replace chemical caustic. The result is that chlorine again is being increased in about the ratio of 2 to 1 compared

to caustic—about the same as the normal market rate of growth for the two commodities.

This rate would result in a balanced situation for caustic and chlorine were it not for the fact that when this expansion was started, chlorine was already short while caustic was in ample supply. To compensate for this difference, some new markets for caustic will have to be developed as described previously.

Toward this end the trend lines for chlorine and caustic soda should be compared. If smooth lines are drawn through the consumption curves for the two products, they cross in about 1957 (see Fig. 1). It is, therefore, logical to expect that chlorine capacity built after that time will have a more difficult time finding a market for its coproduct caustic. Obviously, economic forces will alter the slope of these lines. Prices will have an effect, but technological changes will be made too. For example, the new plant that Hercules Powder Co. is building to make chlorine from hydrochloric acid at Brunswick, Ga., will be closely watched for possibly offering a solution to many organic chemicals producers.

In summary, a market survey has been made. Obviously, the portion presented here is only fragmentary, but the following conclusions seem reasonable:

- By 1953, chlorine-production capacity should be adequate for a few years.
- The possibility of caustic soda surplus is much less serious than would appear at first glance.
- A maximum of sales effort, nevertheless, should be put on developing new markets for caustic.
- Sales managers will recommend more storage capacity for caustic to meet short-term shifts in demand.
- Quality of product will become a more important consideration.
- Cheap transportation will become more important to ease local situations.
- Sales managers will try to sell more caustic to the people who use their chlorine or, conversely, will place chlorine with the caustic user.
- The next large chlorine expansion may be expected to offer greater problems and possibly higher costs to the chlorine consumer because of the caustic problem.

Is it any wonder that marketing is becoming an engineering problem? The forward-looking chemical engineer will find the "engineering approach to sales" both fascinating and worthy of his best professional efforts.



Fig. 5. Existing chlorine plants prior to present expansion, many located near raw-material sources.



Fig. 6. Chlorine plants located near large consuming centers.

Market Survey of New Products

THE introduction of a new breakfast food, a more exotic perfume, or a new chemical is always an important decision. The chemical industry has been called upon many times in the past 30 years to make these decisions, which have resulted in about 7,000 new materials, contributing a substantial portion of the industry's total revenues. Dr. H. B. McClure (1) has pointed out that some chemical firms have reported that 60% of their earnings is derived from products commercialized during the past 20 years. It is axiomatic that the methodology for introducing new chemicals must ensure a minimum of failures. A decade or more ago the chemical industry was able to absorb the loss resulting from mistakes by reconverting facilities to other items. However, this practice is becoming increasingly more expensive as manufacturing units become larger, more costly, and more highly specialized.

The successful introduction of new chemicals requires careful selection by management from the idea stage to the completion of plans for a full-scale plant. Laboratory research has made such rapid strides that a larger number of new items can frequently be developed than there are funds to erect new plants and pay other costs of such ventures. Hence, methods have to be devised to assay each contemplated product. The commercialization of a new chemical is very simple in principle, as all that is involved is, first, producing and, second, selling it. Actually, the process is of course far more complicated.

Teamwork among laboratory and market research, engineering, production, development, advertising, and sales is essential in presenting reports to guide management's decision. In this connection, market research plays a key role. This department is responsible for the prediction of the future sales volume and unit sales price of new chemicals. Accurate analysis of these two items is of primary significance. In a number of instances it is not possible to predict the ultimate market with reasonable accuracy, owing to the newness of the chemical. In such cases the warning to management of the degree of uncertainty emphasizes the greater risk that



will be assumed in comparison with the manufacture of an item of more readily predictable sales potential. If even some indication of the industries that the chemical may serve can be obtained, it will be very helpful in lessening the risk. For instance, Dr. Hitchcock (2) has pointed out that Quaker Oats' decision to manufacture furfural was based partially upon the possibility that it could be utilized in the rapidly growing synthetic-resin industry.

Stability and durability of earnings can be at least partially predicted if the markets for the chemical can be determined by industries to be served. These factors are important, as they frequently have significant bearings upon the availability and cost of capital. Generally speaking, a chemical to be utilized in the manufacture of drugs is less likely to be subject to the same degree of demand fluctuations caused by business booms and depression than one destined to be sold to the iron and steel industry. On the other hand, owing to the rapid advances made by the drug industry, it is possible that chemicals to be used by this industry will have a shorter peak utilization period in the manufacture of any one medicinal than a chemical entering into iron and steel production for a specific application.

Market research can assist the commercialization of new products during four stages of development: (1) idea formulation, (2) laboratory research, (3) pilot-plant scale, (4) semiplant and plant scale. Laboratory research departments are a very important source of new products to manufacture. However, representatives of leading chemical companies have reported that customer contacts by sales and sales-development personnel are one of their most prolific sources of new ideas. Market research can be of great assistance to laboratory research in directing its efforts to attractive fields uncovered as a result of customer contacts. The following four examples will illustrate this type of approach to the development of new pro-

First, ethylene dibromide as a soil fumigant resulted from a market evaluation of the knowledge that crops in the Salinas Valley were being destroyed by infestations of wireworms and nematodes (3). Second, Calgon, a waterconditioning compound, was developed as a result of the market possibilities of chemicals that obviated the difficulties encountered in boilers owing to the formation of boiler scale (4). Third, urea formaldehyde resins were commercialized because of recognition of an economic need for scales lighter in weight than were customary in the late 1920's, so that the salesman might easily carry them when calling on potential users (5). Fourth, the Union Carbide and Carbon Corp. developed glyoxalidines as textile-finishing agents because of the necessity to produce novel finishes on rayon in competition with silks and fine cottons (6). Naturally, market research cannot foresee



G. D. Bieber

George D. Bieber is senior analyst, commercial research department, Eastern Gas and Fuel Associates. He received a B.S. in chemistry from Franklin and Marshall College in 1937 and went on to do graduate work in economics, receiving a Ph.D. from the University of Pittsburgh in 1941. From 1941 to 1944 he was a chemical economist with Koppers Co., and then became technical representative of the tar products division, and later district sales manager of the chemical division before assuming his present position in 1952.

all the markets for a new product. For instance, glyoxalidines, which were developed as textile finishes, later found their largest outlet as tar-emulsion breakers in the water-gas industry (6).

A similar method of uncovering ideas for new products differs from studying known markets in that emphasis is directed toward discovery of the needs of specific industries. This involves an analysis of the products now being utilized and of what new products will be needed in the future. Such investigations direct research activities in certain fields which management wishes to serve. Illustrations of this type of approach can be found in the paper industry, one of the largest consumers of chemicals. Many chemical products have been developed to increase the wet strength, toughness, and tearing and oil and grease resistance and to improve the surface and appearance of paper. Likewise, many items have been marketed to improve petroleum products, including chemicals for increasing the antiknock rating, solvents for dewaxing lubricating oils, antioxidants for gasoline, fuel oils, and lubricating oils, pour depressants, antifoam agents, and anticorrosion compounds.



The pharmaceutical industry has successfully utilized a version of this method. This group has studied the health requirements of the nation and other parts of the world and developed specific materials, such as the anti-biotics and antimalarials, to combat a number of serious illnesses and has also discovered health-improving medicinals in the form of vitamins and similar materials. This type of market and laboratory research and product development has been responsible for the great advances of this industry within the past several decades.

Market research can also undertake basic studies of markets for specific commodities. Research of this type can be of inestimable value in planning future new products. For instance, it would not have been too difficult for a person unfamiliar with chemical research activities to predict at least qualitatively some of the developments in synthetic organic chemicals during the past decade. A simple procedure would have

been to array both natural and synthetic organic materials in descending order of U. S. consumption in, say, 1940. Such a tabulation would have revealed that fuels were consumed in largest volume, with bituminous coal leading the list followed by petroleum products. It could be anticipated that these two groups of products and derived materials, because of their properties, abundance and low unit costs, were



ideally suited for use as raw materials for many of the new chemicals to be developed in the next ten years even if the specific products were then unknown. In the same way natural fibers, soap, and natural rubber, because of their large consumption and price structure, suggested the possibility that similar synthetic products would be developed.

Market research is also frequently of great assistance to laboratory research and top management in deciding whether to continue or cease research expenditures on specific projects. Accurate market reports on changes in the long-range outlook for products under laboratory study can ensure a maximum utilization of research funds and manpower.

After completion of the laboratoryexperimentation period each new chemical is usually reviewed prior to the commencement of pilot-plant studies. Market research, at this stage, can give management a concept of the potential volume and competitive conditions of chemicals in the same field of use as the new product, if not specific data for the new chemical itself.

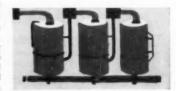
The commercial development of polystyrene can be used as an illustration of this type of market research. A study of the plastics industry in the years prior to World War II would have revealed that this was a rapidly growing field. Such a review would have also pointed out the fields of application and the properties of the plastics required for each major use. Furthermore, a closer scrutiny would have uncovered a large potential market for a thermoplastic material low in cost and possessing good moisture resistance and a relatively high softening point with good colorability and moldability.

The phenomenal growth of polystyrene is unimportant for purposes of this discussion as it is doubtful that anyone could have predicted it accurately at the early stages of commercialization. However, it is significant that a large market did exist and could be served by any product having the necessary properties and production cost. The large size of this market would have been sufficient justification to undertake pilot-plant studies of any promising compound whether it was polystyrene or some other plastic.

Thus far only compounds with known market value have been considered. However, in a number of instances, chemicals emerge from the laboratory stage that are not tailormade for specific uses. Management may have many reasons for desiring to market such compounds, such as interesting properties, manufacture of derivatives of company's raw materials to broaden the latter's utilization, or necessity for finding uses for by-products of useful new materials. Naturally, a compound which shows promise for use in a given field is normally in a preferred position to one with no known uses. The problem of whether to proceed with one of the latter type of compounds resolves itself into the following:

- The importance to the company of finding uses for the compounds for reasons already mentioned.
- The possibility of sound programs being formulated to ensure a successful commercialization of the material with a minimum degree of risk

Whether known or unknown market uses are being considered, the pilot-plant phase is the second stage of the commercial development of a new chemical. The primary function of this stage is to prove the soundness and economy of the process of manufacture. The production of pilot-plant quantities of a new chemical of reproducible grades permits its testing on a larger scale for specific uses. Chemicals utilized for



specific applications other than synthesis are tested in application-research laboratories of either or both the producing company and potential users. Final results are usually obtained by making trial runs in the plants of a few potential customers. In this manner, the chemical can be evaluated under operating conditions. Such data, together with cost figures obtained as a result of pilotplant studies, permit the market research department to refine the figures presented at the end of the laboratory period.

Polystyrene can be utilized again to illustrate this type of testing. Laboratory research had shown that this material should have the necessary properties of a plastic. Tests in plant-owned molding machines proved that the product could be successfully injection molded. Field trials indicated that it could be economically fabricated by molding cycles. Data could also be obtained to show the competitive position of polystyrene in relation to other materials and to present a more definite indication of the utility of molded articles. The very broad laboratory-stage picture of the need for a new thermoplastic material could now be tapered to fit the use properties of polystyrene as they were now known at this stage.

Market information on chemicals to be utilized for synthesis of advanced products must be derived from an analysis of the markets for the end product. For instance, nicotinic acid was the first large-scale use for quinoline. Hence, a study of the market for this would indicate the total demand for quinoline as long as this situation existed.

The new product is again evaluated to determine whether a larger plant should be constructed after the completion of pilot-plant studies. The relationship between estimated capital investment, production costs, and sales volume is the key factor in determining whether the product will offer the necessary inducement to erect a full-scale plant. Capital requirements and production costs can be estimated within reasonable limits at various production capacities from data derived as a result of pilot-plant operations, Similarly, market data at this stage should indicate certain volumes at given prices. The market analyst should employ sound principles to ascertain and check volume figures. Unfortunately, he does not have so precise an instrument to measure volume as the engineer has to calculate production costs and capital requirements. However, he can devise methods that permit him to present the best information obtainable at this point in the commercial development of a new product.

Each demand for the product has its own characteristics, which the market analyst must discover and analyze. Some of these have been already mentioned,

such as the study of the length of the peak utilization period of a new chemical in the various industries which plan to use it. This analysis need not or possibly cannot be done with mathematical precision. However, even qualitative knowledge of this type may be very important in formulating a policy with regard to the future of the new compound. Furthermore, some industries may be able to pay a higher unit price for the new product than other industries. This is due to relationships



in the unit amount required and the selling price of the manufactured product compared to production and distribution costs. Obviously, only market volumes at or above manufacturing and distribution costs for a given total demand are of value in determining the profitability of a new material.

Another important consideration relates to the immediateness of the demand. In a number of instances, an industry can consume specific amounts of a new product as soon as production facilities are available at customers' plants for converting it into more advanced materials for which there exists a waiting market. Nicotinic acid can also serve to illustrate this point. Prior to the availability of quinoline, the acid was produced from beta picoline. The latter was high in price and limited in supply. It was found that quinoline could be utilized as an alternate material in the manufacture of the acid. Hence, a ready-made market existed for quinoline as it permitted production of the acid at a lower price and in larger

It is probably unnecessary to state that market information should be analyzed from several angles as a cross check of its accuracy. However, in many instances, companies fail to recognize the importance of this and frequently later experience attributable marketing and production difficulties. Data on projected sales volume are normally developed at this stage by (1) estimates prepared by consuming companies and (2) data presented by the producing company's market research department. In this manner adjustments can be made for duplicate demands by customers each striving for the major portion of the

market. Naturally, this type of comparative analysis can be made only if the uses for the new product are known.

The market research department must be aware throughout its investigations of the marketing problems involved in plant-scale selling. It is particularly important that this group present its views as to whether the new product can be handled by the present sales force or whether the fields of application are such that specially trained salesmen will be required. If special salesmen are needed, it is important that they be selected and trained accordingly. Such preparation tends to ensure the successful introduction of the product with lower selling costs. The salesman's morale, one of the most important assets of a selling organization, is sustained by the knowledge that he is adequately equipped to present effectively the special merits of the new product.

The final step in the development of a new chemical is assisting the sales



force to market the product after funds for the new plant have been approved and the plant has been erected. Activities of this nature are reviewed elsewhere in this issue (page 643). It is sufficient to say that the market research department can offer to sales management data on basic markets, their location, competitive position of the new chemical, actual customer-interest information, and suggestions on marketing methods and warehousing systems.

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(Presented at A.I.Ch.E. Atlanta Meeting.)

PLASTICS EQUIPMENT REFERENCE SHEET

RAYMOND B. SEYMOUR and ROBERT H. STEINER

The Atlas Mineral Products Co., Mertztown, Pa.

FURANE CEMENT: An infusible plastic material based on a mixture of a liquid polymer of furfuryl alcohol or furfural and a finely divided inert filler such as carbon, silica or acid-washed asbestos. The powder and liquid are supplied in separate containers for on-the-job mixing.

APPLICATION AND REMARKS: A furane cement mortar is prepared by intimately mixing the furane liquid resin with approximately twice its weight of inert filler. The latter contains an acid which catalyzes the subsequent polymerization at ordinary temperatures. The mortar is used for joining acid-proof brick and tile for the protection of chemical vessels, stacks

and floors and also for the molding of process equipment such as tanks, ducts, fittings and pipe. Carbonfilled furane cements have excellent resistance to all non-oxidizing acids, alkalies, salts and most organic solvents. Silica and asbestos-filled compositions are more dense and are attacked by hydrofluoric acid and its salts.

CHEMICAL COMPOSITION: The liquid resin consists of a polymer of furfuryl alcohol or a copolymer of furfuryl alcohol with furfural or formaldehyde plus free furfuryl alcohol or furfural. The powder contains a chemically inert filler and a small amount of a specific acid catalyst such as paratoluene sulfonic acid, sodium acid sulfate or paratoluene sulfonyl chloride.

WORKABILITY: A furane cement mortar can be troweled readily onto brick or tile or grouted into floor tile set in a suitable setting bed. The working time at 77° F. of a typical furane cement is 30 to 50 min. and is inversely related to the temperoture. The mortar attains a preliminary set in a few hours and maximum resistance to chemicals after several days.

MACHINABILITY: Shapes cast from a furane cement can be sawed, ground, turned, drilled and tapped with ordinary metal-working machinery. Pieces can be cemented together using the same mortar if the surfaces are not contaminated with foreign material.

MECHANICAL AND PHYSICAL PROPERTIES

Tensile Strength, lb./sq.in. @ 75° F	1.200
Elongation, %	<1
Impact Notch, Izod, lb./ftin.	0.2
Flexural Strength, lb./sq.in. @ 75° F.	5,000
Compressive Strength, lb./sq.in @ 73° F	14,000
Modulus of Rupture, lb./sq.in.	1.000
Specific Gravity	1.4
Thermal Expansion (is. in. ° F. x 10-6) (32-212° F.)	6
Thermal Conductivity, B.t.u./(sec.) (sq.ft.) (° F./in. x 10.4) (32-212° F.)	1
Resistivity, ohm-cm.	12

TEMPERATURE
LIMITATIONS: Furane cements
can be used
continuously
at temperatures up to
380° F.

CORROSION RESISTANCE

	C	14		C	11		C	H
ACIDS			Copper Chloride, nitrate	_	_		_	_
Acetic, 10%	E	E	Ferric Chloride, nitrate,	E	E	Phenol, 5%	E	EEE
Acetic, glacial Benzene sulfonic, 10	% E	пенене	sulfate Nickel Chloride, nitrate.	E	E	Trichloroethylene	E	E
Benzoic		E	sulfate	E	E	PAPER MILL APPLICATIONS		
Boric	I + X + X + X + X + X	E.	Stannic Chloride	E	E			877
Butyric, 100% Chloroacetic, 10%	E	E	Zinc Chloride, nitrate, sulfate	E	E	Kraft liquor Black liquor	E	REMMEZE
Chromic, 5%		E	ALKALINE SALTS			White liquor	E	5
Citric		E		12	E	Sulfite liquor	E	E
Fatty Acids		E	Barium sulfide	E	E	Chlorite bleach	P	N
Formic, 90%		E	Sodium bicarbonate	E	E	Alum	E	E
Hydrobromic		E	Sodium Sulfide	57	E		Bar.	6.0
Hydrochloric		ZWEGEROUS ZEEZEEZEEZEEZEEZEEZEEZE	Trisodium phosphate	E	EEEE	PHOTOGRAPHIC INDUSTRY		
Hydrocyanic	E	E	Tradition prospinite	-	_		122	
Hydrofluoric	E	E. E.	NEUTRAL SALTS			Developers	E.	E
Hypochlorous	P	N	Calcium chloride, nitrate,			Silver nitrate	E	E
Lactic	E	E	sulfate	177	E	Suver intrate	L	1
Maleic, 25%	E	E	Magnesium chloride, nitrate,	Bio.	E.	FERTILIZER INDUSTRY		
Nitric, 5%		N	sulfate	E	E		-	-
Oleic		E	Potassium chloride, nitrate,		-	General use	E	E
Onalic		E	sulfate	E	E			
Perchloric			Sodium chloride, nitrate,			STEEL INDUSTRY		
Phoaphoric		E .	sulfate	E.	E	Sulfuric acid pickling	E	E
Pieric Stearic	****					Hydrochloric acid pickling	E	
Sulfuric, 50%		E E	GASES			H25O4-HNO2 acid pickling	P	N
Sulfuric, 80%		N N	Chlorine, dry	E	N	manufacture of the second		
Oleum		N	Chlorine, wet	p	N	TEXTILE INDUSTRY		
Mixed Acids, 57% I	1.50.		Sulfur dioxide, dry	E	ZZEE	General use	E	E
26%	INO ₂		Sulfur dioxide, wet		E			
A 0 /6 .			wanter amanan man an arrange			FOOD INDUSTRY		
ALKALIES			ORGANIC MATERIALS			General use	E	E
Ammonium Hydrox	ide	E E	Acetone	F	E	Breweries	E	E
Ammonium Hydroxide		E E	Alcohol, methyl, ethyl	Ē	E	Dairies	E	E
Potassium Hydroxic	le		Aniline	P	N			
Sodium Hydroxide	1	E E	Benzene		E	MISCELLANEOUS INDUSTRIES		
			Carbon tetrachloride	E	E	Plating	E	E
ACID SALTS			Chloroform		E	Petroleum	E	E
Alum or Aluminum		E E	Ethyl Acetate	£	NEEEEE	Tanning	E	E
Ammonium Chloride			Ethylene Chloride		E	Oil and Soap	E	EEEEE
sulfate	**!! **	E E	Formaldehyde, 37%	E	E	Water and Sewer	E	E

RATINGS:

E.—No attack.
G. Appreciably no attack.
F. Some attack but usable in zome instances.
P.—Attacked—not vecommended.

N.—Rapidly attacked.
C.—Cold.—70° F.
H.—Hot.—250° F. or boiling point of test solution.

No. 16

A. I. Ch. E. AWARD WINNERS-1952





3









W. R. Morshall, Jr.

R. H. Wilhelm

J. H. Rushton

Thomas Baros

Harold Hublein

David Stephon

Radney Nelson

POUR major professional awards in chemical engineering were made Tuesday, Dec. 9, at the Annual Awards Banquet of the Institute in Cleveland, Ohio. At the time, recognition was given to Professor Richard H. Wilhelm. professor of chemical engineering at Princeton University, winner of the Professional Progress Award; to Professor J. Henry Rushton, professor of chemical engineering and director of the department of chemical engineering at the Illinois Institute of Technology, winner of the William H. Walker Award; to Thomas Baron of Shell Development Co., and Lloyd G. Alexander of the Oak Ridge National Laboratory. co-winners of the Junior Award; and to Harold F. Hublein a graduate of The Cooper Union for the Advancement of Science and Art, who won the A. Mc-Laren White Award for his solution to the student contest problem.

The formal presentations were made at the banquet by the president of the Institute, W. I. Burt.

The winners of the Professional Progress Award, William H. Walker Award, and the Junior Award, were chosen by the Institute's Award Committee headed by Professor Olaf A. Hougen, department of chemical engineering, University of Wisconsin.

Another outstanding event of the meeting was the fourth Institute Lecture delivered by William Robert Marshall, Jr., associate professor in chemical engineering, University of Wisconsin. His subject was "Spray Drying and Atomization." It is expected that this lecture will form the basis for a volume in the Chemical Engineering Progress Monograph Series.

Professor Wilhelm is the fifth recipient of the Professional Progress Award, which is sponsored by the Celanese Corporation of America and administered by the American Institute of

Chemical Engineers. It is made each year to a chemical engineer under forty-five years of age, "to recognize outstanding progress in the field of chemical engineering, for the betterment of human relations and circumstances." The honor, which carries with it a prize of \$1000, was conferred upon Professor Wilhelm for "his distinguished contributions to the theories and experimental data of fluid mechanics, mass and heat transfer, and reaction rates, and for his special applications of these theories to fluidized solid systems and to biochemical and textile processing."

Last year Professor Wilhelm was also honored by the Institute when he became the sixteenth recipient of the William H. Walker Award.

A native of New York City, Professor Wilhelm received his B.S. degree in 1931 from Columbia School of Engineering, his Ch.E. in 1932, and in 1935 he received his Ph.D. degree in chemical engineering from the Columbia Graduate School, where he was Pulitzer scholar.

Professor Wilhelm was director of the Princeton Bicentennial Conference (1946) on "Engineering and Human Affairs" and is a licensed professional engineer in the State of New Jersey. He is at present a member of the management committee of chemical sciences laboratory of the Forrestal Research Center and is a consultant to the Research and Development Board of the Department of Defense and to various chemical companies. In 1949 he was instrumental in organizing a program of studies at Princeton combining elements of chemical engineering and biology. His memberships include the American Chemical Society, New York Academy of Sciences, and American Society for Engineering Education, In 1952-53 Professor Wilhelm was president of the Princeton Chapter of Sigma Xi.

This year's winner of the Walker

Award, Professor J. Henry Rushton, is the seventeenth chemical engineer to be so honored, and this makes four straight years that the teaching profession has achieved this recognition. Professor Rushton was chosen, in the words of the citation, "in recognition of his excellent publication record over the years in the fields of equipment design, mechanical mixing, and engineering education, and for his recent contributions to Chemical Engineering Progress, especially the articles 'Power Characteristics of Mixing Impellers' published in 1950, and 'Pilot Plant Mixing Data,' in 1951."

This award is made in memory of the late Professor William H. Walker, of the Massachusetts Institute of Technology, one of the pioneers in developing the modern concept of chemical engi-

Professor Rushton is a graduate of the University of Pennsylvania, where he received both his B.S. and Ph.D. degrees in chemical engineering. After several years of industrial work he returned to university work, teaching at Drexel University, University of Tichigan, and University of Virginia before assuming his present position at Illinois Institute of Technology.

Professor Rushton is a well-known authority on the chemical engineering aspects of mixing. He has authored well over forty technical articles on the subject and has pioneered many of the newer concepts in the field. He is coauthor of the textbook "Process Equipment Design" with Herman C. Hesse.

During the war he served with the Office of Scientific Research and Development as a technical aide and section chief in charge of the oxygen program for the National Defense Research Committee. At present he is expert consultant, Research and Development Board, Department of Defense.

(Continued on page 35)



BILOXI, ON THE GULF, FOR MARCH MEETING

MINERAL engineering techniques for chemical engineers will be the main feature of the Biloxi, Miss., meeting of the A.I.Ch.E., to be held at the Buena Vista Hotel, March 8-11, 1953. The symposium, one of a series planned by the program committee featuring a major theme of interest to the chemical engineering profession, is the work of Chairman Norman C. Morash, supervisor in the development and engineering department, technical division, Titanium Division, National Lead Co.: co-chairman T. S. Leary, assistant manager, central pilot plant, Calco Chemical Division, American Cyanamid Co.; and co-chairman D. W. Oakley, assistant plant manager, Metal & Thermit Corp. According to Morash, "the purpose of the symposium is to acquaint the chemical engineer with equipment, unit operations, and unit processes common to the mineral engineer. All too often the chemical engineer attempts a lengthy solution to a difficult equipment or process design problem when, if he had been aware of techniques practiced in some allied field, he would have known that a ready solution to his problem was available. This symposium will try to fill in the gap in most chemical engineers' education on that portion of industry which lies between the domains of the mining engineer and the metallurgist."

Norman Spector of the Vitro Corporation of America. Technical Program chairman for the complete meeting, has planned several other symposia for the same meeting including one on streamlining paper shuffling, under chairman F. R. Fisher, secretary, Sinclair Research Laboratories, Inc., and another on fluid mechanics under Professor R. W. Moulton, department of chemical engineering, University of Washington.

The symposium on mineral engineering techniques will probably be held over the first two days of the meeting. It will begin with an all-day session on flotation, at which ten experts will present papers ranging from an introduction to flotation through descriptions of installations, plus discussions on flotation kinetics, theories of flotation, and specific uses of flotation techniques. The second day, Tuesday, will be a day of four 15/2-hour round-table discussions. The first round table will cover fine sizing and the use of cyclones and centrifuges and will be under the direction of H. S. Spedden of Union Carbide & Carbon Chemicals Co. The second round table of the morning, led by S. R. B. Cooke, of the Minnesota School of Mines, will investigate sizing devices including screening, classification, and clarification.

The afternoon of Tuesday will be given over to two additional round tables, one a discussion on sink and float separation methods led by W. T. Turrall of the Lehigh Navigation Coal Co. Specifically, this will touch only heavy media separation. The final round-table discussion on miscellaneous concentrations.

ing devices will be led by Alan Stanley of National Lead Co.

The additional symposia planned by Dr. Spector are of like interest to members of the Institute. The symposium on "Streamlining Paper Shuffling" is intended to help chemical executives adopt modern efficient methods of handling the paper details that are becoming increasingly burdensome in the executive's business day.

Dr. J. D. Sullivan, of Battelle Memorial Institute, is planning a chemical process symposium that will cover the chemical processing of manganese and copper scrap, and sulfate roasting in a fluid bed. This series of papers falls into the same general theme as the mineral engineering techniques and will probably be held on the final, or third, day of the meeting.

A general technical session is being planned by A. Norman Hixson, professor of chemical engineering at the University of Pennsylvania, and a session on fluid mechanics by Professor R. W. Moulton, department of chemical engineering, University of Washington, will cover velocities of centrifugal spray nozzles, venturi atomization, transfer of momentum in a jet of air, and other recent technical advances in moving fluids.

Final details of the program are not yet crystallized, and "C.E.P." will carry a notice about the meeting in the February issue.

Meeting Headquarters

The headquarters hotel for the Biloxi meeting is the Buena Vista, a resort hotel eighty miles from New Orleans, La., and sixty miles from Mobile, Ala. Essentially a vacation spot, the hotel is equipped to handle small convention groups up to about 500 attendance. This meeting is in line with previous Institute gatherings at resort cities, where the temptation to visit plants and the distractions of an industrial city are missing. Primarily, the specific purpose of the resort-type meeting is to keep attendees concentrating on the subject at hand and also to provide for them nonscheduled recreation for the off hours.

Members of the Institute will be able to register either under the American



N. C. Morash



T. S. Lean

plan at \$12.50 a person, a day, or under the European plan with double rooms

available from \$6.50 to \$12.50 a day and single rooms from \$3.50 to \$7.50.

If the weather is warm, swimming in the Gulf of Mexico will be a major feature since the hotel is on the shore. Sailing, deep-sea fishing, and cruises on the Gulf will also be part of the program. Instead of a banquet during the meeting, preliminary plans call for a "sea-food jamboree" which will feature all the coast sea foods, served smorgasbord style. Golf courses are accessible to the hotel, which is located on U. S. Highway 90. The Southern Railroad and the Louisville and Nashville Railroad have trains with direct connections to Biloxi, and National Air Lines services Gulfport, Miss., near the hotel.

Any overflow from the Buena Vista will be cared for at the Whitehouse, a Colonial-style resort hotel under the same management and within walking distance of the Buena Vista. This too has a private beach on the Gulf, and, in addition, cottages with complete hotel service are available.

HOLBROOK FORESEES CONTINUED EXPANSION IN CHEMICAL INDUSTRY

Continuation of national expansion of the chemical industry is assured, despite rumors of overextension, according to Dr. George E. Holbrook, former head of the chemical division of the National Production Authority and present assistant director of the development department of Du Pont Co., who appeared recently on a national A.B.C. network program, "Production Report."

The industry's four-year program, which will result in expenditures exceeding \$5,000,000 by 1955, is second only to the expansion plan of the steel industry, he said, and added, "I believe that the chemical industry is much more competent now than ever before to find alternate raw materials to replace those that might be cut off in the event of an international crisis. I also feel that the industry is definitely better prepared to grapple with difficult technical problems, and I believe we can even say that world leadership in chemistry and chemical engineering now is really a keystone in the industrial strength of the United States."

Two representatives of the Manufacturing Chemists' Association, Inc., who also appeared on the program, Dan M. Rugg, vice-president and general manager of the chemical division of Koppers Co., Inc., Pittsburgh, and Dr. Robert C. Swain, vice-president of the American Cyanamid Co., New York, agreed with Dr. Holbrook's estimate.

LEVER BROTHERS' NEW RESEARCH CENTER



A view of the working quarters convenient to New York for the new research center of Brothers Co., Edgewater, N. J., which was formally opened on Nov. 18. The five-story building nearest the Hudson River is the laboratory; the two-story glass-and-steel structure in the foreground is the pilot plant, with its experimental spray tower at one end. The research center, employing more than 300 scientists and technicians, will house all the research and technical development for all divisions of Lever Brothers Co.

AWARD WINNERS (Continued from page 33)

For a number of years he engaged in industrial consulting work for several chemical equipment manufacturers. He

is now also director of research for Mixing Equipment Co.

At present Professor Rushton is a director of the American Institute of Chemical Engineers; he is chairmanelect of the Industrial and Engineering Division, American Chemical Society: and he is a member of the Society of Chemical Industry, American Society for Engineering Education, American Society of Mechanical Engineers, and The Chemists' Club, New York.

The Junior Award, given for outstanding contributions to the literature of chemical engineering, is made annually for "the paper judged most outstanding of those published by junior members of the Institute during the last three years, in Chemical Engineering Progress."

Baron and Alexander won for their study entitled "Momentum, Mass and Heat Transfer in Free Jets," published

Mr. Baron, a native of Hungary, received his B.S. in chemical engineering from the University of Illinois, 1943, his Ph.D. from the same institution in 1948. Upon completion of his graduate work he joined the teaching staff of the University of Illinois as instructor and later as assistant professor. While so engaged he became a consultant to the Army Chemical Corps, and in the summer of 1951 joined the Shell Development Co. He is a member of Tau Beta Phi, Sigma Xi, and Phi Lambda Upsilon.

Mr. Alexander, a native of Indiana. received his B.S. in chemical engineering from Purdue University, his Ph.D. in 1947 also from Purdue. Until 1950 he was assistant professor in chemical engineering at the University of Illinois, then became assistant professor of chemical engineering at the University of Oklahoma, where he has been chairman of the school since September 1951. He is currently on leave to the Oak Ridge National Laboratory,

Student Contest Winners

Harold F. Hublein, the winner of the A. McLaren White Award, is at present employed as a field development engineer in the engineering service division, E. I. du Pont de Nemours & Co., Inc. The problem this year concerned the peacetime use of atomic energy and required the engineering design of an atomic power system for the conversion of kinetic energy released by nuclear fission into useful electrical or mechanical power.

Second prize went to Rodney A. Nelson, graduate student at the University of Minnesota; third prize to David G. Stephan, a student in the graduate school at Ohio State University, where he is Battelle Memorial Institute fellow in chemical engineering. Honorable mention went to Joseph H. Jaffer, Jr., student in the graduate engineering school at Yale University; Robert H. Schwaar presently enrolled in the graduate engineering school at Princeton University; and Eugene I. Motte, now doing graduate work at the University of California



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GREENEWALT RECEIVES S.C.I. & WHARTON MEDALS

Growth and improvement will characterize this nation's economy as long as our research laboratories continue active in our universities and in our industry, said Crawford H. Greenewalt, president of Du Pont Co., Wilmington, Del., in accepting the Chemical Industry Medal off the American Section of the Society of Chemical Industry last month.

Our research laboratories and the creative thinkers working in them are providing for us a storehouse of plenty in our present living and the greatest possible potential for our future growth, Mr. Greenewalt asserted. This represents, he said, the creative thought and achievement by individuals in science brought to fruition by industry.

"In science, as in economics and politics, there has been in recent years a tendency to minimize the function and the importance of individuals. But whether we are dealing with industrial laboratories or with the university campus, we must not lose sight of the fact that no matter how elaborate our facilities, or how highly organized our programs, research progress is still the product of human ingenuity and depends for its success upon individual achievement," said Mr. Greenewalt.

"I doubt that there is any area in which there is greater need for self-sufficiency than in our contributions to fundamental knowledge. For many things we can find substitutes, but there is not now, nor will there ever be, a substitute for creative thought. . . . It is unfortunate that the financial necessities of some of our universities appear to have driven them more and more into the field of sponsored and applied research. This is a disquieting trend, and I think it is one of industry's prime responsibilities to do what it can to reverse it."

Mr. Greenewalt also received the third annual gold medal of merit from the Wharton School Alumni Society for "distinguished leadership in the promotion of public understanding of business." In his acceptance speech he considered personal freedom today vs. the collective good. "How best can we preserve personal freedoms in face of the needs and demands that appear to call for collective rather than individual effort?" asked Mr. Greenewalt, and he answered that "Americans have achieved their high standard of living, their strength, and their premier position before the world through their devotion to freedom. We must be very sure that any move which limits that freedom does not promise more than it can fulfill or cost more than it is worth."

WITH

SYNTHETIC FIBERS FOR ALLIED CHEMICAL & DYE

Allied Chemical & Dye Corp. announced last month its entry into the synthetic-fiber market through the construction of a plant for manufacture of a polyamide (nylon) type fiber. Allied's national aniline division will erect and operate the new facilities and market the product.

All facilities will be located in the Hopewell, Va., area. A site of approximately 600 acres immediately to the north of Hopewell has been optioned for fiber production. Raw-materials processing will be conducted on a site already owned adjacent to the giant Hopewell plant of Allied's nitrogen division. Approximately 750 people will be employed.

The fiber is a high-molecular-weight polyamide belonging to the class known generically as nylons. Processes for its production and for the necessary new chemical raw materials were developed at Allied's central research laboratory. Projected annual production of facilities to be installed at this time is 20,000,000 lb., which will be offered both as staple and as continuous-filament yarn. Production of certain polymer grades in suitable form for molding into plastics is also visualized.

The cost of the new manufacturing facilities is estimated as being in excess of \$23,000,000, of which 40% will qualify for accelerated amortization under certificate of necessity issued by Defense Production Authority July 21, 1952. The certificate of necessity was one of four granted on that date to increase domestic capacity for production of nylon-type synthetic fibers.

NUCLEAR CENTER FOR EUROPE

Thirty nuclear physicists from ten European nations met October 4 to 7 in Amsterdam, Holland, and unanimously selected a site near Geneva, Switzerland, for a great European nuclear research laboratory. The laboratory is to house what may be the most powerful atomsmashing cosmotron in the world-a huge accelerator that will be rated at thirty thousand million electron volts. There will also be a synchro-cyclotron with a rating of six hundred million electron volts. The laboratory will take about seven years to build and equip and will cost the participating countries an annual total of almost four million dollars. It is to be used exclusively for pure scientific research. None of the results will be secret but will be supplied freely to all member-nations of the European Council for Atomic Research, an organization founded recently with the help of UNESCO.



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CARBIDE DEVELOPS ELECTRIC COAL-MINING MACHINE

A continuous coal-mining rig that sends an electrically controlled mining machine 700 ft. horizontally into the side of a hill, boring out a stream of coal that is brought to the face by a series of traveling conveyors, has been announced by Carbide and Carbon Chemicals Co., a division of Union Carbide and Carbon Corp. The machine was developed in conjunction with Carbide's coal-hydrogenation program for making aromatic chemicals.

The mining machine is electrically powered, moves on tractor treads, and has four intermeshing rotary cutting heads mounted on the front. It carves out a 3- by 10-ft, hole in the coal seam and forces the mined coal onto the traveling conveyor system.

This machine mines up to 13/3 tons of coal a minute and has poured out 567 tons in an 8-hr. shift. The operators of this machine are always above ground.

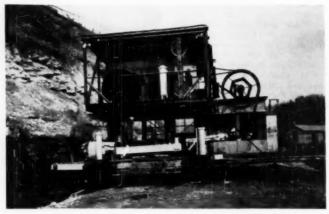
The machine was designed for use on out-crop seams. The two-story rig operates from a shelf cut into the side of the hill where the coal seam comes out. By using four hydraulic jacks, one

mounted on each corner of the platform,

and a track and wheel assembly, the machine can be maneuvered along the shelf. It can be moved from one boring to the next in about 20 min.

As the mining machine digs its way into the seam, it pulls a train of 30-ft. long conveyor-belt sections. Each section is driven by a separate electric motor. The coal is moved in successive steps from the mining machine to the launching platform. The depth of the borings is limited now to 700 ft.

At the launching platform, the coal



New continuous coal-mining rig announced by Carbide and Carbon Chemicals Co. This tractortreaded mining machine can bare its way 700 ft. into an outcropping coal seam. The mined coal is brought out by a series of 30-ft. electrically driven conveyor-belt sections. This development ties in with Carbide's recently announced coal-hydrogenation process for making aromatic chemicals.

FOAM DEVELOPED FOR SOLVENT FIRES

Air fire-fighting foam which will not dissolve in solvents was recently demon-Air nre-ngnting foam which will not dissolve in solvents was recently demonstrated in Newark, N. J., by the Pyrene Manufacturing Co. The foam, a protein-base material, is resistant to solvent breakdown, and is fed to the spray pipe in liquid form, the foam being formed by the jet action of the water stream. The compound may be used with salt water as well as fresh, and is effective against gasoline, alcohols, acetone, M.E.K., ethers, and acrylonitrile.

The new foam is piled up in the foreground and industrial safety engineers test

its adhesive and elastic properties.



falls into a transfer conveyor which delivers the coal to a truck-loading hopper.

The mining machine is steered by an operator who watches two oscilloscopes. On these radarlike scopes, light beams trace circular paths corresponding to the paths of two electrical sensing devices mounted on the outer teeth of the cutting heads. Every time the stratascope teeth cut through anything harder or softer than normal coal, they cause an irregularity to show up in the light circles on the oscilloscopes.

If the launching platform cannot reach the face of the seam, telescoping sections of runway can bridge the gap. First, pilot drills tap the face of the seam and then the main cutting heads begin cutting into the face. Fixed cutting blades, above and below the rotating cutters, smooth the top and bottom of the cut. Rotating paddles, mounted on the same shafts as the cutting heads, force the mined coal inward into the conveyor system.

At the conclusion of a cut, the mining machine is reversed and it pushes out the conveyor sections. Each section is removed and nested until it is needed on the next cut. A tractor-mounted crane places these conveyor sections on the launching platform or removes them.

It the seam is thick, two cuts may be made from the same platform position.



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greases; and may be used for temperatures up to 380° F. ALKOR 5E has no offensive odor; and its low shrinkage assures joints that are level with the brick or tile surface.

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ATLAS PRODUCTS STAND



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(Continued from page 38)

NEW PROCESS FOR SULFUR REMOVAL

A new catalytic desulfurization process for eliminating sulfur content in sour middle distillates is now available through The M. W. Kellogg Co., a subsidiary of Pullman, Inc., as a result of a licensing arrangement concluded with Anglo-Iranian Oil Co., Ltd., it was announced recently.

The process, known as Autofining, will be used on high-sulfur crudes, now being imported from the Middle East and South America as well as from West Texas and Rocky Mountain fields.

According to M. W. Kellogg officials, the potential importance is in the production of jet fuels. Today most jet fuel is obtained from sweet crudes, but with the market growing steadily, a fullscale war would force refiners to use other crudes and mixtures of crudes. The demand could never be met without extensive desulfurization.

RESEARCH CENTERS FOR EUROPE

A new research center to serve German industry is under construction at Frankfurt-am-Main by Batelle Memorial Institute of Columbus, Ohio. Chemical, metallurgical, and engineering research projects will be handled by the \$1,500,000 laboratory, the site of which was presented by the city of Frankfurt.

The purposes of the Institute in establishing European research centers are, according to Dr. Clyde Williams, director, the economic betterment of the European economy through industrial research and the general advancement of science and technology on both sides of the Atlantic. "We hope to develop a healthy interchange of ideas and techniques for research . . ." he said.

Batelle is also establishing a similar center at Geneva, Switzerland, and has set up a program of fellowships for selected students in the universities of both Switzerland and Germany.

SOIL-CONDITIONER MANUFACTURERS MEET

A national trade association of chemical-soil-conditioner manufacturers and formulators is expected to result from the soil-conditioner conference sponsored by Henry A. Dreer, Inc., of Philadelphia, manufacturers of Fluffium, in New York last month. The Federal Trade Commission is to be petitioned jointly by a number of manufacturers to implement the establishment of standards and practices for the industry.

C.C.D.A. TO MEET

Two meetings are planned for 1953 by the Commercial Chemical Development Association. The first 1953 meeting will be held in Cleveland, Ohio, on Jan. 22, at the Hotel Statler, and according to John A. Field, chairman, Public Relations Committee, the meeting will be given over to a presentation of a discussion of the use of chemicals in the various phases of the rubber and petroleum industries. This meeting is open only to members and their guests.

An annual meeting is also being planned by the Association, for New York City on March 23-24, 1953, at the Hotel Statler. The central theme of the meeting will be "Economics and Commercial Chemical Development."

AUTOMATIC-COMPUTA-TION SYMPOSIUM

A two-day symposium on the use of automatic-computing equipment in industry will be held in Kansas City, Mo., on Jan. 8 and 9. Sponsored by the Midwest Research Institute in cooperation with local sections of the American Institute of Chemical Engineers, the American Institute of Electrical Engineers, the American Society of Civil Engineers, the American Society of Mechanical Engineers, the Institute of Radio Engineers, the Instrument Society of America, and the Society of Automotive Engineers, the conference will cover the operations of digital computers and analogue computers, organization of a computations center, and the application of computers to problems in the various branches of engineering. Further information may be obtained from Martin Goland, Midwest Research Institute, 4040 Pennsyvlania, Kansas City, Mo.

A.I.Ch.E. MEETS WITH CANADIAN INSTITUTE

The first joint conference of the A.I.Ch.E. with the Chemical Engineering Division of The Chemical Institute of Canada will be held in Toronto on April 27-29, 1953.

Over 700 delegates are expected to attend the technical sessions and visit plants in Toronto, Hamilton, and Niagara Falls. The Canadian institute is in charge of arrangements for the conference, and Brymer Williams of the University of Michigan, Ann Arbor, Mich., represents the A.I.Ch.E. committee.

FACULTY LISTING READY

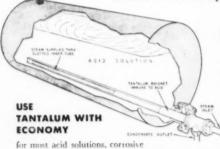
The new listing of chemical engineering faculty in the colleges of the United States, announced in the October issue, is now available and may be obtained from the Secretary at 120 East 41 Street, New York 17, N. Y.





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Secretary's Report

S. L. TYLER

THE Executive Committee of the Institute met in New York on Nov. 14 with all members present. The minutes of previous meetings, reports and bills were received and approved. The recommendations of the Committee on Admissions regarding those applicants for membership appearing in the October issue of "C.E.P." were received and those recommended by the Committee were elected to the grades of membership as indicated; also 171 applicants were elected to Student Membership.

The Secretary reported the death of G. J. Esselen, a former director of the Institute, and formal recognition of this was voted

Upon recommendation of the Chairman of the Membership Committee, Henry Avery was appointed to replace K. R. Burke (Pittsburgh Section) and A. G. Parker was appointed to replace R. Morton (New York Section).

Upon recommendation of the Chairman of the Public Relations Committee, R. P. Stevens was appointed to replace R. York as the St. Louis representative and J. E. Troyan was appointed to replace W. C. Greenwald of the Western New York Section.

Upon recommendation of the Chairman of the Student Chapters Committee, F. C. Hettinger was appointed to replace B. L. Harris as counselor of the student chapter at Johns Hopkins University.

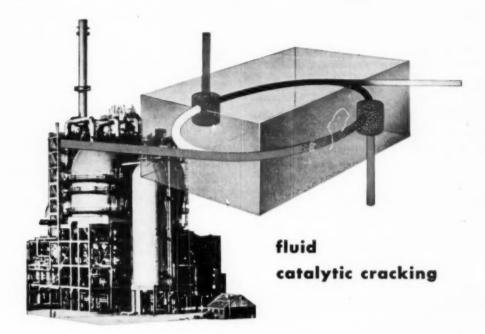
The name of Richard F. Beiler was placed on the Suspense List because of his entering the Armed Forces. It was a pleasure to report the return to actively participating member status of A. V. Forbes and T. V. McGannon, as they have completed their tour of duty in the Armed Forces.

The November meeting of Council was held at The Chemists' Club in New York City on Nov. 14. The first actions covered the approval of minutes and other routine matters.

J. L. Olsen, Chairman of the Membership Committee, attended this meeting and discussed at length with Council the activities of his committee and the plans for committee activities during 1953. One point which he stressed particularly was the very satisfactory return following the use of the short-form application for Junior Membership designed particularly for the use of students either just prior to or immediately following graduation.

(Continued on page 45)

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CANDIDATES FOR MEMBERSHIP IN A. I. Ch. E.

The following is a list of candidates for the designated grades of membership in A.I.Ch.E. recommended for elec-tion by the Committee on Admissions.

These names are listed in accordance with Article III,

Section 7, of the Constitution of A.I.Ch.E.

APPLICANTS FOR ACTIVE MEMBERSHIP

Altimier, David F., Niagara Falls, N. Y.

Anderson, Stanley P., Buffalo, N. Y. Bailey, Raymond V., New

Orleans, La. Bauer, John A., Whiting,

Bateman, Walter R., Nederland, Tex.

Bennett, Robert B., Akron, Ohio

Brondyke, Willis F., Wilmington, Del. Carlisle, O. T., Texas City,

Tex. Carlson, Howard D., West

Chester, Pa. Cook, Kalph L., Alton, 111.

Dicks, Robert S., Houston, Tex.

Dinius, James H., Neenah, Wis.

Garwin, Leo, Ohlahoma City, Ohla.

Graham, M. Ernest, Parma, Ohio

Ohio
Haggerty, J. P., Harrisonburg, Va.
Harlow, Howard W., Midland, Mich.
Hart, E. G., New Brunswick, N. J.
Haynes, M. D., Westfield,
N. J. Husen, Paul C., Borger,

Tex.

Kapfer, William H., New York, N. Y. Kennedy, Glenn F., Bound Brook, N. J.

Krieg, L. R., Baton Rouge,

Lager, Samuel E., Sherman Oaks, Calif.

Massa, Anthony P., Bronx, N. Y.

Objections to the election of any of these candidates from Active Members will receive careful consideration if received before January 15, 1953, at the Office of the Secretary, American Institute of Chemical Engineers, 120 East 41st., New York 17, N. Y.

Mitchell, J. Ernest, Jr., Midland, Mich. Montgomery, C. R., Belle Vernon, Pa.

Paraly, Lewis F., Jr., Oak Ridge, Tenn.
Rhodes, Bryce L.,
E. Providence, R. I.

Springer, Donald E., Niagara Falls, N. Y. Tegge, B. R., Chatham,

Tidball, Robert A., Evans City, Pa. Wikdahl, L., Stockholm,

Sweden Wishnick, John H.,

Chicago, Ill. Wood, John E., III, Baton Rouge, La.

APPLICANTS FOR ASSOCIATE MEMBERSHIP

K. V. Antony, Sindri, Bihar, India Estabrook, James P. Drummondville, P. Q.,

APPLICANTS FOR JUNIOR MEMBERSHIP

Archer, David H., Newark, Del.

Armstrong, Gerald, Marshall, Tex. Arnold, Stanley I., Seattle,

Austin, David S., Stamford,

Conn Baer, Sheldon, Cleveland, Ohio

Belansky, Joseph J., Whiting, Ind.
Bellizzi, Mario, New York, N. Y.

Bertrando, Bertrand R., Pasadena, Calif.

Bieber, Harold H., New York, N. Y. Braun, Robert T., St. Louis,

Mo. Brown, Vance B., Army Chemical Center, Md. Bunin, Donald S.,

So. Charleston, W. Va. Butler, Frank A., Verona, N. J. Caines, William H.,

Blacksburg, Va. Calcote, Robert E., Jr., Baton Rouge, La.

Coffey, David D., Jr., Kingsport, Tenn. Connell, Walter R., Jr., Cuyahoga Falls, Ohio

mond, Va. Cozzarelli, Frank, Jr.,

Cunningham, D. C., Army Chemical Center, Md.

Darnell, William H., Madison, Wis.

ville, N. J. De Mier, Warren V., Rich-land, Wash.

Akron, Ohio

Fereshetian, Robert H., Philadelphia, Pa. Ferguson, F. Alan, Redwood City, Calif.

Jackson, Tex. Glass, Benjamin, New York, N. Y.

Gordon, Saul, Army Chemical Center, Md. Graglia, Mario John, Long Island City, N. Y. Greco, Joe, Gainesville,

Flor Hanschka, Richard M., Jr., Maplewood, N. J.

Hill, Peter W., Marcus Hook, Pa.

Hollenbeck, Bonderinko, Waltham, Mass. Jackson, Reginald O.,

Jones, Richard M., Atlanta, Ga.

111.

Heights, Ohio Kaiser, Elbert W., Port Huron, Mich.

King, Ben H., Groves, Tex. Knobeloch, Donald C., St. Louis, Mo.

Cox, William B., Rich-Belleville, N. J.

Cunningham, Fay L., Kalamazoo, Mich.

Davis, Donald W., Belle-

Diamond, Arthur S., Brooklyn, N. Y Dittmar, Charles A.,

Doczy, Joseph S., Munhall, Pa.

Fredlund, Raymond, Lake

Goldberg, Isadore, Brooklyn, N. Y.

Haselbarth, John E., Pasadena, Tex Hegg, George L., Minne-apolis, Minn.

Hogroian, Paul, New York, N. Y.

Somers, Conn.

Jurco, Milan R., Riverside, Kahn, Henry, Cleveland

Karnavas, James A., Chemical Center, Md.



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SECRETARY'S REPORT

(Continued from page 42)

J. M. Weiss, Chairman of the Professional Legislation Committee, also attended this meeting and reported on the activities of his committee. The general tone of his report was that matters were in very good shape as there is now a tendency toward uniformity in the license laws in the various states along the lines of the Model Law recommended by the various engineering groups.

Upon recommendation of the Chairman of the Local Sections Committee, the application for local section status from the Coastal Georgia Chemical Engineers Club was approved, and this section will be known as the Coastal Georgia Section. Also, the application from the Midland Chemical Engineers Club was approved-this section to be known as the Midland Section.

The Council approved the recommendation of the Program Committee that a special meeting in June of 1954 be sponsored by the Institute. This meeting will be held at the University of Michigan, Ann Arbor, Michigan, in conjunction with the One Hundredth Anniversary of the teaching of engineering at the University of Michigan, and the program will be devoted to the engineering aspects of nuclear energy problems and especially the activities of the chemical engineer in this field.

D. M. Grav was appointed as representative of the Institute on the Engineering Manpower Commission for

J. B. Tepe was appointed as the Institute representative on the A.S.A. Subcommittee 1 of Committee Y32 Graphical Symbols for Process and Engineering Flow Sheets of the Chemical and Petroleum Industries.

J. H. Perry was appointed as chairman of the committee in charge of preparation of the History of the Institute with authority to expand this committee as he felt necessary.

The balance of the time of the meeting was taken up with the appointment of chairmen of the standing committees of the Institute for 1953.

Deferment of Engineers

All those seeking deferments for employees, particularly those in engineering and scientific work, are urged to prepare the statements submitted to the local boards to establish the importance of the registrant in accordance with the outline in Opinion and Comment in the September issue of "C.E.P.," page 431.

Quality Improved Production Increased With Speed-Trols

Mr. W. F. Haverkamp, Chemical Engineer of Columbia Wax Co., Glendale, California, reports variable speed Speed-Trols driving blending agitators eliminated the need for belt and supplementary gear systems, increased production capacity of equipment by greatly reducing processing time, and improved product quality. In over two years the only maintenance has been periodic lubrication.

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(Continued from page 44)

Korzun, John N., New York, N. Y. Kushida, Raymond O., Newark, Del. Lee, Donald M., Army Chemical

Center, Md.
Lester, Robert M., Jr., Richmond, Va.
Letts, Roger W. M., Old Greenwich,

Livingston, Charles B., St. Louis, Mo. McLean, Thomas J., Houston, Tex. Monti, Dario R., Houston, Tex. Morgan, Lucian L., Forth Worth, Tex. Morgan, William H., Youngstown, Ohio

Mourier-Petersen, Paul A. F., Army Chemical Center, Md. Murray, James E., Texas City, Tex. Nakata, Morimatsu, Los Angeles, Calif. Ohlswager, Stanley, Matteson, Ill. Olsen, Glen W., Charleston, W. Va. Ong, John N., Jr., Salt Lake City, Utah Parziale, Ernest Vincent, Boston, Mass. Peterson, Rodney E., Army Chemical

Center, Md.

Petkus, Edward J., Maywood, Ill.

Przybyla, Richard L., Detroit, Mich.

Ramsey, Knowles, Elkton, Va.

Ripepi, Philip J., Army Chemical

Center, Md.

Schillon, Gerald Simon, Asbury Park,

Schubert, R. F., Fairview Park, Ohio Sims, John Hugh, St. Louis, Mo. Smeal, Harry Wm., Pittaburgh, Pa. Soldano, Anthony V., Denver, Colo. Stief, Robert D., So. Charleston, W. Va. Stolinski, John R., St. Louis, Mo. Suchan, Harold L., Buhl. Idaho Tobias, Charles W., Berkeley, Calif. Van Steenburgh, Russell E., Buffalo, N. Y.

Vrubliauskas, Joseph F., Neshanic Station, N. J. Wain, Donald J., Edgewood, Md. Ward, Harold L., Jr., Chicago, Ill. Williamson, Harold Eugene, Houston,

Tex.
Young, Richard Kenneth, Boulder

City, Nev.
Zenoni, William F., Atlanta, Ga.

AWARDS FOR BEST BOOKS

Two annual awards for the best books in the field of economics of chemicalprocess industries have been announced by R. S. Aries and Associates. New York consulting firm of chemical engineers and economists.

Advance royalties of \$1500 and \$500 will be paid to the winners of the first and second awards, respectively. The winning manuscripts will be published by Chemonomics, Inc., an affiliate of R. S. Aries and Associates. To be eligible, a book must be at least 20,000 words in length and must be written especially for the contest.

Judges will be headed by Professors David D. B. Hertz of Columbia University and John Happel of New York University. The contest closes July 1, 1953, and awards will be made in September. Further details may be obtained from Chemonomics, 400 Madison Avenue. New York 17, N. Y.

SHAPING THE FUTURE

THOMAS A. MATTHEWS, II

Pure Oil Laboratories, Crystal Lake, Illinois * Chairman, Public Relations Committee, Chicago Section, A.I.Ch.E.

IN the spring of 1950 William H. Congleton and S. W. Kapranos of the Chicago Section organized a Vocational Guidance Sub-committee of the local Public Relations Committee. The purpose has been to provide chemical engineers to speak informally before groups of interested high school students on the subject "Engineering as a Career." All these men have given freely of their time and abilities in a public service without thought of compensation. This is one mark of a profession and has done much to increase the prestige of chemical engineering in Chicago.

Guidance Techniques

Two test talks were given in the suburbs in the spring of 1950. During the school year 1950-1951 about sixty schools were contacted by Chicago A.I.Ch.E. members. Of this number twenty-five responded favorably and sixteen made final arrangements for a talk. The procedure followed is to write to the vocational guidance counselor of each school and, if the school is interested, to have a chemical engineer personally interview the counselor.

The chemical engineer assigned for a particular talk prepares some notes on opportunities and disadvantages; educational and personality requirements; professional standing; and social, political, and economic position and responsibilities of chemical engineers. The general air of the speech, however, is informal, with a father-to-son or big-brother attitude. A story illustrating the importance and interest of science comprises the "meat" of the talk. Humorous or exciting adventures spice up the presentation. A general discussion with active student participation follows.

The speaker usually leaves an "engineering problem" which requires little or no scientific background to solve. For example: A man is in a canoe which floats in a small indoor pool. The canoe is half-filled with water, and a large rock is in the bottom of the canoe. The man heaves the rock overboard into the pool. Of course, the water level in the canoe

falls, now that the rock is removed. However the man is amazed to note that the level in the pool has also fallen. Problem: Where did all the water go?

The vocational guidance work of the Chicago Section was expanded during the school year 1951-1952. At the present rate of progress, probably between thirty and forty schools will receive its services this year. Most of the chemical engineers involved in this work become very interested in the high school students and their problems. Consequently, several of them have arranged to serve as counselors to local school science clubs. They sponsor chemistry projects, suggest lines of research, and continue with personal vocational guidance work.

Additional aids to this guidance work are films and slides and industry tours. A film, however, should supplement a talk, not take its place. Several industrially supported committees have been advised of the usefulness of a vocational guidance film. Tours are at present being conducted by ten companies, some of which had never conducted tours until contacted by A.I.Ch.E.

Another innovation has been vocational guidance radio broadcasts. One, of an informal question-and-answer type, has been given. Professional radio people are good at this type of work, and all plans should be discussed with them.

In an effort to establish greater understanding between the chemical engineering profession and high school educators, two teachers or counselors are invited to attend each Chicago Section meeting. The many informal discussions which have developed have done much to enlighten both school and industry personnel.

Social Responsibility

The vocational guidance work of the Chicago Section represents one of the greatest fields of contact between the chemical engineering profession and the general public. Every participating member is impressed with the responsibility which he assumes. This is the opportunity for chemical engineers to practice some of the social responsibility mentioned in the code of ethics.

Young men are served by this work because they must have information about the various professions before an intelligent choice of career may be made. It is just as important to discourage the unfit as to encourage the capable. Nothing is more tragic than a man striving desperately to get ahead in work that he hates.

Industry is served because able young men are directed into engineering fields. Management is interested in obtaining engineers who like their work and who have been properly advised concerning liberal arts and business administration courses.

The nation as a whole is served because a constant supply of good engineers is encouraged.

The Public Relations Committee is engaged in a great public service in the Chicago area, which the unselfish participation of many men has made successful. Typical of the men who give their time and ability is a chief engineer of a Chicago concern who has designed sixteen new industrial plants in the past five years and yet has found time to contact personally and to address four separate high school groups. The industries also deserve mention for their donation of the time of many of their top men.

The reward for the Institute and industry is increased recognition and improved public relations. Proving that men of industry are willing to serve high school students can do much to influence these young men, 65% of whom are said to favor government operation of all industries.* Many new ideals will be instilled and misconceptions corrected as young men are aided by sincere, unselfish chemical engineers.

This article in the series on A.I.Ch.E. activities sets forth the efforts of the Chicago Section to contribute to the community through its youth. The members of this group have organized a vocational guidance program that attempts to take industry to the high school and thus make the student aware of the advantages and disadvantages of an engineering career before he decides on technical training.

The present discussion continues the chain of thought outlined in previous articles which covered counseling student chapters, accrediting graduate courses in chemical engineering, and bringing the teacher to industry. These and corollary articles appeared in the issues for March, September, and December 1951 and March, July, and September

^{*} According to a national poll conducted by Junior Achievement in 1950.

^{*} Present address: The Western Co., Midland, Texas.

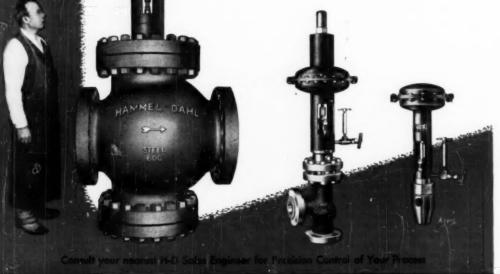
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BULLETINS

- 1 TELECORDEX. Dual indicating and recording accumulator counts and stores sequential electrical pulses. Called Telecordex. Bulletin from Telecomputing Corp. describes in detail; gives specifications and other data.
- 2 U-TUBE MANOMETER. New leaflet chart from Uehling Instrument Co. pictures U-tube manometer available in scales from 10 to 100 in. for water, or in required units for other fluids. Standard calibrations.
- 3 AIR POWERED STIRRER. Arrow Air Stirrer air powered from Arrow Engineering Co., Inc. For viscous materials. Used in solvents, lacquers, paints, synthetics, etc. Air supply 35 to 100 lb., 7-1 air ratio motor, 50-1200 rev./min.
- 4 SPECTROPHOTOMETER APPLICA-TIONS. Beckman Instruments, Inc. new bibliography of applications for spectrophotometers. More than 500 sources of application data. Industrial and laboratory problems presented.
- 5 BIN-FLO. Bulletin from Bin-Dicator Co. on Bin-Flo aerator unit. Low pressure diffused air prevents bin clogging and provides continuous flow of ground materials. Diagrams, illusrations, etc.
- 6 PULVERIZERS. Super-Master for pulverizing from Gruendler Crusher & Pulverizer Co. Bulletin gives specifications, photographs, etc. Memo book gives list of materials which can be processed. Paint and varnish, glass, food, rubber, soap, etc. industries.
- 7 PROCESS EQUIPMENT. Bulletin from Sprout-Waldron on equipment and systems for processing of dry/ semidry materials, Horizontal, vertical and continuous batch mixers.

- 8 COOLING TOWERS. Water Cooling Equipment Co. Line of water-cooling towers in new bulletin. Mechanical and atmospheric types. Specifications, capacities, physical data, etc. listed.
- 9 ROTARY DRYER. Standard type KDH dryer described in leaflet from Standard Steel Corp. Rotary, continuous, direct heat, 2 to 10 ft. diam., varying lengths. Diagrams, dimensions, types covered.
- 10 TURBO-MIXERS. For fermentation industry but also pharmaceuticals, plastics, food and rubber industries, new Turbo-Mixer from General American Transportation Corp. Illustrated bulletin gives applications, diagrams, etc.
- 11 INDUSTRIAL EQUIPMENT. From R. C. Mahon Co. new illustrated bulletin or: finishing systems; dust collectors, hoppers, tanks, pressure vessels, dry-off ovens, etc.
- 12 VEGETABLE OLEIC ACID. Emery Industries, inc. Emersol 240, an oleic acid of vegetable origin. Feature: oxidation stability and bland odor. Bulletin includes specifications, etc.
- 14 ENGINEERING SERVICES. Badger Mfg. Co. new brochure lists members of its engineering depart-

- ments, services available to chemical, petrochemical, food, beverage, pharmaceutical and other industries.
- 15 CATALYSTS. Catalysts for every industry, available from Harshaw Chemical Co., and described in new booklet. For special uses, assistance offered in development of suitable catalysts.
- 16 INSULATED PIPE. Prescaled insulated pipe for underground and weather-exposed locations, available from Durant Insulated Pipe Co. Division of Durant International Corp. described in new leaflet. Standard lengths and sizes up to 24 in.
- 17 RUBBER EXPANSION JOINTS. Goodall Rubber Co. line of standard spool-type rubber expansion joints with Flang-Lok ends and flanges. For handling, under vacuum or pressure, and temperatures to 200°F., water, oil, gasoline, refrigerants, etc. Described in new bulletin. Easily installed, corrosion resistant, many types.
- 18 LABORATORY EQUIPMENT. Supplementing earlier catalogs, a booklet from Scientific Glass Apparatus Co., Inc. Describes and illustrates laboratory equipment, microscopes, cover glass, thermometers, beakers, bottles, etc.

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19 • MATERIALS HANDLING. Lift jacks; skid platforms, haulers, pry bars, etc. described in new leaflet from Ironbound Box & Lumber Co. Specifications, types, etc.

20 • PUMPS. Both air-hydraulic and power pump units listed and described in bulletin from Ledeen Mfg. Co. Ratings, dimensions, diagrams, with applications.

21 • PORTABLE PUMP. For pilot plants, unloading carboys, continuous processing, etc. new portable pump from Portable Pump Co. Delivers I qt. to 10 gal./min. heads to 55 ft. Made of stainless steel, resistant to most corrosive solutions, for use in chemical and pharmaceutical, textile, petroleum and other industries.

22 • VALVES. Automatic valves and controllers for regulating pressure, flow, and liquid level, described in bulletin from A. W. Cash Co.

23 • RUBBER EQUIPMENT. Rubbercovered pipe, fittings, etc., rubberlined tanks, ductwork, etc., a complete line covered in catalog from Automotive Rubber Co., Inc. Usage charts give information and data.

24 • DEMINERALIZER. New, 100 gal./ hr. monocolumn demineralizer, ca-

pacity 4500 gr. announced by Penfield Mfg. Co.

25 • BI-ROTOR METER. Ralph N. Brodie Co., Inc. describes line of bi-rotor meters for measuring fluid flow in new leaflet. Welded-steel construction, balanced design and performance, faster flow and adaptable to any piping system. Also accessories.

26 • TUBE ROLLING. A new controlled method for expansion and rolling of tubes into tube sheets fully described in leaflet from Vernon Tool Co., Ltd.

27 • AXONOMETRIC DRAWING. A method of three-dimensional illustration for showing projections of machine parts, pipelines, tanks, pumps, columns, etc. in an easily visualized manner. Product of John R. Cassell Co., Inc., drawings are made with special types of stencils which give isometric or dimetric views.

28 • CENTRIFUGAL PUMPS. New leaflet of line of centrifugal pumps from Byron Jackson Co. Special features include quick dismantling, corrosion-resistant catch basin, cored passages, mechanical seal protection against leakage.

29 • TRUCKS. Two- and four-wheel trucks for materials handling in all industries, made by West Bend Equipment Corp. Construction, specifications, types, capacities, all listed.

30 • RADIAL ENGINES. New 20-page bulletin from Nordberg Mfg. Co. covers two cycle diesel, spark-fired gas, and duafuel radial engines. Have 11 or 12 cylinders, power range up to 2125 hp. or 1500 kw at 400 rpm. For industrial and municipal power plants.

CHEMICALS

35 • GLACIAL METHACRYLIC. Now available in pilot plant quantities from Rohm and Haas Co., glacial methacrylic acid. For use in non-aqueous polymerizations and copolymerizations. 99% purity (by titration), boiling range, 760 mm. 159-163°C.

36 • MAGNESIUM TRISHICATE. J. T. Baker Chemical Co. free-flowing magnesium trisilicate. Used in pharmaceutical and drug manufacture.

37 • ORGANIC SILICOFLUORIDES. Newly introduced by Davison Chemical Corp. a series of organic silicofluorides. Six now available are methylamine, dibutylamine, ethylhexylamine, aniline, Rosin Amine, and morpholine silicofluorides. Wide variation in properties. Interesting laboratory-tested potential use in shoe polish to prevent mildew and fungus conditions in footwear.

38 • SILICONE. Silicon Oxyhyride by Linde Air Products Co. Outstanding as a filler and blowing agent for rubber, possesses properties for other industrial uses as a catalyst base, waterproofing component of greases, creams, etc.

39 • TECHNICAL DATA SHEETS. Commercial Solvents Corp. data sheets on diethyl oxalate and butanol. Give specifications, physical properties, reactions, toxicity, etc.





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40 • FIBER BOARD BOND. A new resin for tempered fiberboard bonding. Gives shrinkproof, boilproof boards, Snyder Chemical Corp. Called Synco 131, the compound will give cold, intermediate, or hot sets.

41 • DYEING SYNTHETIC FIBERS. General Dyestuff Corp. technical bulletin on the dyeing of synthetic fibers. Covers Dacton, Dynel, Orlon, Vicara, Saran, etc.

42 • IGNITION IMPROVER. For improving the ignition of diesel fuel Ethyl Corp. has a new additive. Compound consists of a mixture of primary amyl nitrates which will improve the cetane number of middle oil distillates. Uses one-tenth of 1% by volume and will bring heating oil within the cetane numbers of commercial diesel fuels. Booklet discusses application and advantages of the ignition improver, charts of its effectiveness, studies in full-scale engines, physical and chemical properties, plus a bibliography.

43 • CARBON-14. Available for the first time without authorization from the A.E.C., a radioactive Carbon-14 labeled d-glucose. Nuclear Instrument & Chemical Corp. offers about 40 mg. of this material without licensing directly from stock.

44 • TRIBUTYL PHOSPHATE. Ohio-Apex, Inc., is producing tributyl phosphate in commercial quantities as an antifoam agent in the production of paints, water-soluble adhesives, inks, casein solutions, and rubber latex.

45 • POLYVINYL ALCOHOLS. American Monomer Corp. has standardized on six grades of polyvinyl alcohol to be marketed under the trade name Lemol. The six ranges represent the most widely used combinations of high and low viscosity coupled with complete and partial hydrolysis. To be used in compounding with polyvinyl acetate emulsions as thickening agents, grease-resistant paper

coatings, films, oil- and greaseproof gaskets, paper sizing, etc.

46 • POLYESTER PLASTICIZER. A polyester resin plasticizer newly developed by Bonner Chemicals, Inc. Gives nitrocellulose a film of high gloss, high flexibility and high tensile strength. High range of solubilities and compatibilities, soluble in alcohols and hydrocarbons both aromatic and aliphatic. For technical coating trade, manufacturers of aircraft finishes, waterproofing, flameproofing, etc. Specification sheet available.

47 • GASOLINE SWEETENER. Tennessee Eastman Co. new process for sweetening and inhibiting gasoline in single step. Possibility of conversion of mercaptans to disulfides with Tenamene 2, discussed. General recommendations for use.

48 • DYEING DACRON. Techniques of dyeing Dacron with benzoic or salicylic acid as carriers described in new technical bulletin from Heyden Chemical Corp.

49 • SODA BLEACH SOLUTIONS. Guidebook of sodium hypochlerite solutions, issued by Diamond Alkali Co. covers general properties of hypochlorites, analyzes control of solution stability. Gives tables, includes charts, reviews requirements in diverse industries, etc.

50 • HYDROGEN PEROXIDE. Hydrogen peroxide in purification of plating and other metal salt solutions, described in new bulletin from Buffalo Electro-Chemical Co. Inc. Includes directions for isolating metal salts from process solutions in electrolytic nickel plating, beryllium production, etc.

51 • FISHER REAGENTS. Five new reagents from Fisher Scientific Co., C-551-cupferron ammonium salt of N-nitrosophenylhydroxylamine; A-47 amino naphtholsulfonic acid for use in making azo dyes; A-295 sulfamic acid used for flame proofing fabrics and wood, and as a weed killer; P-97 m-phenylenediamine hydrochloride a reagent for nitrite; soda lime for variety of uses; S-195 Soda Lime 4-8 mesh; S-196 is 8-14 mesh.

52 • ORGANIC CHEMICALS. Eleven new organic chemicals added to line of Distillation Products Industries, Division of Eastman Kodak Co.

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53 • SOLVENTS. Recently developed by Tennessee Eastman Co., two new solvents, 3-methyoxybutyl acetate and 3-methyoxybutyl alcohol. Bulletin lists several formulas and suggested uses.

54 • IMPROVED QUARTERNARIES. Industrial Division of Onyx Oil & Chemical Co. announces two quaternary ammonium salts. Table shows comparative phenol coefficients, wetting action. Covers chemical and physical properties toxicological data, uses, etc.

55 • FOOD PRESERVATIVES. Monsanto Chemical Co's. Organic Chemicals Division, new illustrated booklet on use of benzoic acid and sodium benzoate for protection of food against spoilage, preservation of soap, rubber, etc.

EQUIPMENT

63 • VERSA TABLE. Fisher Scientific Co. Versa-Table unit which performs eight different laboratory roles, depending upon method of installation. The unit is 30 in. x 48 in. in size, can be installed as part of other laboratory furniture. Used at two heights.

64 • HOMOGENIZER. A super homogenizer with a capacity of 800 gal./ hr. for use in food, pharmaceutical, pigment, and mineral oil industries. Cherry-Burrell Corp. Single or two-stage valve, all surfaces of stainless steel. Maximum operating pressure 2500 lb./sq.in.

65 . INDUSTRIAL HOSE REEL. For the

plant with a problem of storing hose when it is not being used for flushing or filling purposes, Zierden Co. has a new hose storage reel which may be mounted behind walls, overhead, on islands, etc. Hose can be unreeled faster than under ordinary coiling conditions, from a free rotating wheel. Is replaced by pushing back into the reel where it automatically coils. Five different reel mountings available. Permanent pipe connections are made to a spindle housing, and hose connections are made at lower end of the spindle tube.

66 • OXYGEN ANALYZER. Arnold O. Beckman, Inc. announce oxygen analyzer designed for combustion applications in power plants, steel mills, petroleum refineries, etc. Standard potentiometer recorder, controller, or pneumatic receiver can be used. High selectivity, automatic operation.

67 • MERCURECEIVER. Useful with all types of manometers Chemiquip Co. Mercureceiver. Prevents loss of mercury from manometer tube, gives steady average pressure readings, smooths pressure impulses. Easy installation and removal for cleaning.

68 • INVERTER SWITCH. Bristol Co. syncroverter switch having sensitivity of 0.05 μv. and dissymmetry of less than ½ of 1%. Capable of converting low-power d-c signals to alternating voltages for amplification and application to electronic, electrical, ctc. systems.

69 • GAS-DETECTOR ALARMS. Combustible gas protective instruments from Johnson-Williams, Ltd., portable indicator, portable audible alarm, two combustible gas alarms. Description of style and operating principles, accessories, uses, specifications and prices.

70 • SPEED BRIDGE. Weiller Instruments Corp. speed bridge indicating temperatures to .001°C, over restricted range.

71 • SPEEDWEIGH SCALES. New with Toledo Scale Co., Speedweigh overunder scales. Offers speed and accuracy in industrial packaging, check-weighing. Sensitive to 1/64 oz. indicator travels 1 in. to 1 oz.

72 • STEAM-JET CLEANER. Portable Speedylectric steam cleaner from Livingstone Engineering Co. Portable, pressures to 150 lb./sq. in., for light duty cleaning of machinery, fluorescent tubes, lighting fixtures, etc.

73 • TEFLON PARTS. From Sparta Heat-Treat Co. molded parts made from Teflon, machine-finished, heat-resistant to 500°F., low-temperature toughness to —320°F. Nonadhesive, erosionresistant, weather-resistant, dielectric properties at high temperatures and frequencies.

74 • RATCHET-LEVER HOIST. Coffing Hoist Co. coil-chain, ratchet-lever hoist, 1500-and 3000-lb. capacities.

75 • COMPARATOR - MICROPHOTO-METER. Comparator-microphotometer from National Spectographic Sales Corp. Measures spectrum density on film or plate for determination of chemical elements.

76 • VARIABLE SPEED DRIVE. Dodge Mfg. Corp. varible speed drive. Four units comprise new drive. Single adjusting screw, easy pitch diameter change. Deep side walls, Dodge Sealed-Life belts, etc.

77 • PRECISION THERMOSTAT. Automatic analysis of flue gas catalyticcombustion principle, by Fenwal Thermoswitch from Bailey Meter Co. Accuracy within 0.25% oxygen content. Continuous graphic record.

78 • LEAK DETECTOR. Data sheet describing Halogen-Sensitive leak detector from Distillation Products Industries. Reveals leaks in high-racuum systems by response to traces of probe gases.





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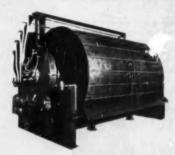
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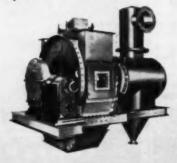
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LOCAL SECTION NEWS

CALENDAR OF MEETINGS

The following is supplementary to the list of meetings of local sections published in the October issue, page 65, and November issue, page 70:

El Dorado, Ark. The third Friday of each month.

Contact: A. A. Feerick, Lion Oil Company, El Dorado, Ark.

Maryland. Jan. 20, Feb. 17, March 17, April 21.

Contact: F. C. Dehler, the Davison Chemical Corp., 101 N. Charles St., Baltimore 3, Md.; Louis J. Trostel, General Refractories Co., P. O. Box 1673, Baltimore 3, Md.; L. Calvin Palmer and Raymond L. Copson, Mutual Chemical Company of America, 1348 Block St., Baltimore 31, Md.

New Jersey. Jan. 13, Feb. 10, March 10, April 10.

Contact: O. C. Karkalits, 132 Oak Manor Parkway, South Plainfield, N. J.

Oklahoma. Meetings are usually held on the third Thursday of each month. Contact: Howard Irvin, 1617 S. Rogers,

Bartlesville, Okla.

MIDLAND

"Power from the Atom" discussed by a panel of experts attracted 195 members and guests at the first meeting of the fall program held at the Dow Auditorium.

The meeting started with the showing of the picture "Operation Crossroads."

J. J. Grebe then gave a brief summary of the purpose of the Dow-Detroit

Edison team which is now studying the possibilities of power from the atom.

A. W. Hanson of The Dow Chemical

A. W. Hanson of The Dow Chemical Co. spoke on why private industry must take an active part in the development of "Power from the Atom."

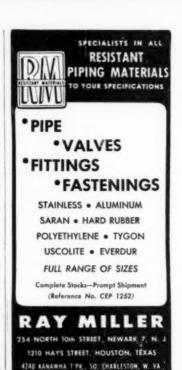
E. L. Nugent of The Detroit Edison Co. gave a description of the basic reactions of atomic energy. He gave numerous examples of "fertile" materials, "fissionable" materials, "moderators" and showed their relationship to each other.

A. P. Donnell of The Detroit Edison Co. described the operation and design of the various types of atomic reactors.

The last speaker was H. A. Wagner of the Detroit Edison who told about the economics of "Atomic Power." He stressed that at the present time there was no way of going from atomic energy directly to electric power.

At the October meeting Dr. Letcher A. Jones, research supervisor of Standard Oil Co. of Ohio, discussed thermal diffusion, pointing out the primary factors for gas and aqueous solutions and for organic solutions.

Reported by Raymond Duddleston









WESTERN NEW YORK

A joint meeting with the Electrochemical Society and the National Association of Corrosion Engineers was held in November, with Dr. Thomas P. May, technical director, International Nickel Research Laboratories, as speaker. Fundamental principles of electrolytic corrosion was the theme of Dr. May's talk, and he discussed electrode potentials and their relation to corrosion rates, as well as the forms of corrosion attack commonly encountered in process equipment. Of the ninety-six persons present, fifty represented A.I.Ch.E.

On December 6 a plant-inspection trip was planned at the Buffalo refinery of Socony-Vacuum Oil Co., which is a new Thermofor catalytic cracking unit with air lift for catalyst.

Reported by James W. Casten

MARYLAND

The second meeting of this section was held on Nov. 11, at the Engineers' Club, and the speaker for the evening was Charles R. Schwartz of the Du Pont Co., whose topic was "Management and Control by Cost Accounting and Planning."

The third meeting of the Maryland Section will be the annual business meeting at which new officers will be elected. After dinner and the election of officers and completion of other business, the group will view a film by the International Nickel Company and also see the film "Du Pont History."

CENTRAL OHIO

Harry C. Ballman, smoke regulation engineer of the city of Columbus, is scheduled to speak on "The Mechanics of Air Pollution Control" at the second meeting of the season. Continuing last year's activities, the section is again participating in a series of television programs produced by the Columbus Technical Council, an association of technical societies in this area. G. E. Sachsel is in charge of this activity.

Reported by G. F. Sachsel

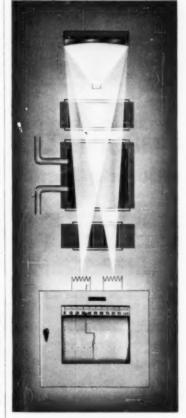
SOUTH TEXAS

A tour of the Ethyl Corp. plant was scheduled to start the November meeting, which also included a social hour, dinner, and technical session. The subject of the evening address was engine-combustion research, which was discussed by Wheeler Lovell. A report was also made on the Seventh Annual Technical Meeting, held in Houston on Oct. 24 and attended by a record total of 720 people.

Reported by W. R. Trutna

END POINT ANALYSIS

ACCURATE - AUTOMATIC - CONTINUOUS



CH=CH

CH₂=CHCN
CH₂=CHCI

CH₂= CH₂
CH₂OH — CH₂OH
C₂H₅OH

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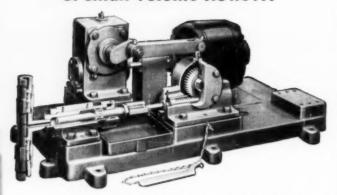
- The decisive factor in the economic success of a process is product quality and yield.
- End-point analysis for concentration variations is a reliable index of product quality and yield.
- Through end-point control, the results of such analyses can be automatically and continuously used to correct the process variables.
- For these reasons, continuous end-point analysis and its control application are of major significance to the process engineer.
- The Baird Associates Plant Stream Analyzer is specifically designed for continuous end-point analysis and control.

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PHILADELPHIA-WILMINGTON

The October meeting, the first of the season, was a dinner meeting attended by about 130 members and guests. Dr. W. F. Love of the University of Pennsylvania reviewed recent progress made in methods for producing low temperatures and described phenomena associated with ultra sub-zero temperatures.

The second meeting of the season was a joint meeting with the Delaware Engineering Association attended by approximately 400 persons. A. C. Monteith, vice-president of Westinghouse Electric and Manufacturing Co., spoke on the general topic of the engineer's civic responsibility and indicated that a personal interest should be taken in a new engineer to the extent of introducing him in the community and otherwise encouraging him to participate in community affairs.

At the third meeting, held in Philadelphia and attended by about seventy persons, the speaker was H. Davidson of Davidson and Hemmendinger, color consultants, who spoke on the theory and nature of color, emphasizing the industrial applications and present-day measuring techniques.

Reported by William E. Osborn

COASTAL GEORGIA CHEMI-CAL ENGINEERS' CLUB

The annual meeting was a dinner meeting in Brunswick, Ga., after which a film on the intracoastal waterway was shown by P. E. Redding, Corps of Engineers, U. S. Army. The new officers for 1953 are:

Chairman—A. R. Bookout, Jr., Hercules Powder Co., Brunswick, Ga. Vice-Chairman—J. C. Bowers, Union Bag & Paper Corp., Savannah, Ga. Secretary—D. W. Reid, Union Bag & Paper Corp., Savannah, Ga. Treasurer—J. B. Loucks, Hercules Powder Co., Savannah, Ga.

Reported by A. H. Riley, Ir.

PITTSBURGH

William I. Burt, vice-president in charge of manufacturing for B. F. Goodrich Chemical Co. and president of A.I.Ch.E., addressed the November meeting. Under the topic "Institute Affairs." Mr. Burt outlined the historical background of the Institute as well as its various functions and committees and discussed the effect on the organization of the present technical manpower situation and the plans of the Institute to help overcome the shortage.

Reported by James R. West, Herbert A. Morrissey, and James H. Black

NORTHERN CALIFORNIA

Approximately 125 members and guests attended the October meeting held at the Oleum refinery of the Union Oil Company of California. After a guided tour of the refinery, dinner was served in the company cafeteria, and later M. S. Thomson, superintendent of lube treating, discussed refinery operations, with emphasis on preparation of lubricating oils.

Reported by D. F. Rynning

SOUTHERN CALIFORNIA

The November meeting was scheduled to continue the subject of "Rocketry," inaugurated at the October meeting, with a talk on "Chemical Engineering Factors Involved in Rocket Propulsion" by Thomas E. Myers, of North American Aviation. Mr. Myers planned to discuss liquid propellant rocket research, design, and development.

The December meeting is to be a dinner meeting at which the speaker will be Robert E. Vivian, dean of engineering, University of Southern California, Los Angeles. Dean Vivian will discuss the chemical industry in Italy, where he spent six months as chemical production specialist for the Mutual Security Agency. In his official capacity Dean Vivian was able to visit many chemical plants, particularly those dealing with explosives and related heavy chemical industries.

Reported by Gale S. Peterson

KANSAS CITY

T. L. Gore of the Standard Oil Co. (Indiana) spoke at the October meeting on some aspects of the behavior of natural gases.

TWIN CITIES

Forty-six members attended the October meeting, which featured Lyle Fisher, director of industrial relations at Minnesota Mining and Manufacturing Company. The program was the second in a series of discussions on labor relations in the chemical industry, and Mr. Fisher offered management's point of view, after which the meeting was opened for discussion—primarily of the economic status of the chemical engineer.

At the November meeting, William I. Burt, President of A.I.Ch.E. and vice-president in charge of manufacturing for the B. F. Goodrich Chemical Co., gave an address on "Institute Affairs," which was expected to be of special interest to junior and student members. Election of section officers was also planned for this meeting.

Reported by R. H. Fredrickson

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FUTURE MEETINGS AND SYMPOSIA OF A.I.Ch.E.

Chairman of the A.I.Ch.E. Program Committee

Loren P. Scoville, Jefferson Chemical Co., 260 Madison Ave., New York 16, N. Y.

MEETINGS

Biloxi, Miss., Buena Vista Hotel, Mar. 8-11, 1953.

Technical Program Chairman: Norman A. Spector, Vitro Corp., 233 Broadway, New York 7, N. Y.

Toronto, Canada, Royal-York Hotel, April 26-29, 1953.

Technical Program Chairman: Brymer Williams, Dept. of Chem. and Met. Eng., University of Michigan, Ann Arbor, Mich.

San Francisco, Calif., Fairmont and Mark Hopkins Hotels, Sept. 13-16, 1953

Technical Program Chairman: R. W. Moulton, Head, Dept. of Chem. Eng., University of Washington, Seattle, Wash.

Annual-St. Louis, Mo., Hotel Jefferson, Dec. 13-16, 1953.

Technical Program Chairman: R. M. Lawrence, Monsanto Chem. Co., St. Louis 4, Mo.

SYMPOSIA

Chemical Engineering in Hydrometallurgy

Chairman: John D. Sullivan, Battelle Memorial Institute, Columbus, Ohio.

Co-Chairman: John Clegg, Battelle Memorial Institute, Columbus, Ohio.

Meeting-Biloxi, Miss.

Fluid Mechanics

Chairman: R. W. Moulton, Head, Dept. of Chem. Eng., University of Washington, Seattle, Wash. Mecting—Biloxi, Miss.

Mineral Engineering Techniques for Chemical Engineers

Chairman: N. Morash, Titanium Div., National Lead Co., P. O. Box 58, South Amboy, N. I. Co-Chairmen: T. S. Leary, Calco Chem. Div., Bound Brook, N. J., and D. W. Oakley, Metal & Thermit Corp., Carteret, N. J. Meeting—Biloxi, Miss.

Ion Exchange and Adsorption

Chairman: N. R. Amundson, Dept. of Chem. Eng., Univ. of Minnesota, Minneapolis 14, Minn. Meeting—San Francisco, Calif.

Mixin

Chairman: J. H. Rushton, Dept. of Chem. Eng., Illinois Inst. of Tech., Chicago, Ill. Meeting—San Francisco, Calif.

Transport Properties

Chairman: J. L. Franklin, Res. Assoc., Humble Oil & Refining Company, Baytown, Texas Meeting—San Francisco, Calif.

Distillation

Chairman: D. E. Holcomb, Dean of Eng., Texas Technological College, Lubbock, Tex. Meeting—St. Louis, Mo.

Dust and Mist Collection

Chairman: C. E. Lapple, Dept. of Chem. Eng., Ohio State University, Columbus 10, Ohio. Meeting—St. Louis, Mo.

Drving

Chairman: L. E. Stout, Dept. of Chem. Eng., Washington University, St. Louis 5, Mo. Meeting—St. Louis, Mo.

Use of Computers in Chemical Engineering

Chairman: John R. Bowman, Head, Dept. of Res. in Phys. Chem., Mellon Institute of Industrial Research, Pittsburgh 13, Pa. Meeting—St. Louis, Mo.

Absorption

Chairman: R. L. Pigford, Div. of Chem. Eng., Univ. of Delaware, Newark, Del.

Authors wishing to present papers at a scheduled meeting of the A.I.Ch.E. should first query the Chairman of the A.I.Ch.E. Program Committee, Loren P. Scoville, with a carbon copy of the letter to the Technical Program Chairman of the meeting at which the author wishes to present the paper. Another carbon should go to the Editor, F. J. Van Antwerpen, 120 East 41st Street, New York 17, N. Y. If the paper is suitable for a symposium, a carbon of the letter should go to the Chairman of the Symposia, instead of the Chairman of the Technical Program, since symposia are not scheduled for any meeting until they are complete and approved by the national Program Committee. Before authors begin their manuscripts they should obtain from the meeting Chairman a copy of the Guide to Speakers. The first bock covers the preparation of manuscripts, and the second covers the proper presentation of papers at A.I.Ch.E. meetings. Presentations of papers are judged at every meeting and an award is made to the sensker who delivers his paper in the best manner. Winners are announced in Chamical Engineering Programs, and a scroll is presented to the winning author at a meeting of his local section. Since due copies of the manuscript must be prepared, one should be sent to the Chairman of the symposium and one to the Technical Program Chairman if the symposium is involved and the other three copies should be sent to the Editor's office. Manuscripts not received 70 days before a meeting cannot be considered.

PEOPLE

James M. McWhirter, formerly Southern works manager for the Pennsylvania Salt Manufacturing Co., has recently been appointed manager of the Wyandotte works, and J. T. Gormally, formerly superintendent of the Cornwells Heights plant, has been named assistant to the production manager, in the Philadelphia office. Mr. McWhirter went to Pennsalt from the General Chemical Co. in 1945 and was superintendent of the Natrona, Pa., and Calvert City, Ky., plants prior to his present position.

Chemical plants division of Blaw-Knox Construction Co. has announced



the promotion of Charles F. Hauck to assistant sales manager of the division. In addition, he will continue his duties as the division's manager of sales promotion.

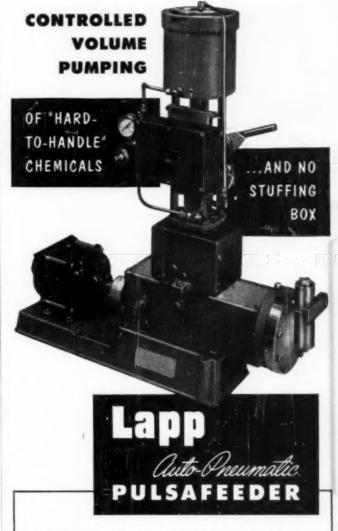
Mr. Hauck will coordinate the sales efforts of the branch

offices of the division at New York, Philadelphia, Birmingham, San Francisco, and Pittsburgh. Prior to joining the division a year ago, Mr. Hauck had 15 years of experience in chemical engineering and wet-processing industries. He received a B.S. degree from John Carroll University and is a registered professional engineer in Pennsylvania and Ohio.

AWARD TO G. N. HARCOURT

Guy N. Harcourt, vice-president in charge of engineering of the Buflovak equipment division of the Blaw-Knox Co., Buffalo, N. Y., was the first recipient of the Professional Achievement Award to be given annually by the Western New York Section of A.I.Ch.E. in recognition of service to the profession as a whole.

Before going to Buffalo in 1939, Mr. Harcourt was manager of the New York office of Buffalo Foundry and Machine Company, which later became affiliated with Blaw-Knox. Although he received his bachelor's and master's degrees (from Massachusetts Institute of Technology) in civil engineering, Mr. Harcourt early turned to chemical engineering, a field in which he has won international prominence for his knowledge of chemical equipment and processes particularly in regard to drum drying and kettle designs.



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EGER MURPHREE TO RECEIVE MEDAL

Dr. Eger V. Murphree, president of Standard Oil Development Co., was named recipient of the Industrial Research Institute Medal for 1953 for "outstanding accomplishment in leadership in or management of industrial research which contributes broadly to the development of industry or the public welfare." Among the contributions to the petroleum industry made by Standard Oil Development Co. since Dr. Murphree became president in 1947 have been fluid catalytic cracking and fluid hydroforming processes and such new products as special lubricating oils, petrochemicals, and butyl synthetic rubber. Dr. Murphree is a graduate of the University of Kentucky and Massachusetts Institute of Technology and is president of the Permanent Council of the World Petroleum Congress.

Dr. C. Rogers McCullough's return to the general development and patent department of Monsanto Chemical Co. was announced. Dr. McCullough has been director of Monsanto's atomic-electric project since June, 1951. in charge of investigating the use of atomic energy for the production of electric power for the A.E.C. A graduate of Swarthmore College and Massachusetts Institute of Technology, Dr. McCullough has been with Monsanto since 1935. During World War II he was project manager for the development of rocket propellants at Monsanto's central research department.

HUGHEY AND KAZAN AT CHEMSTRAND

The Chemstrand Corp. announces the appointment of Dr. George B. Hughey as area technical superintendent of intermediate operations and George Kazan, Jr., as area superintendent of the adipic acid plant, Pensacola, Fla. Dr. Hughey was formerly with West Virginia Pulp and Paper Co. and received a Ph.D. in chemical engineering from Ohio State University. Mr. Kazan is a graduate of New York University and was development supervisor for general chemical division, Allied Chemical and Dye Corp., North Claymont, Del.

Norton H. Walton has recently assumed the position of general foreman of the acid and ammonia division of the chemicals department of the Atlantic Refining Co., Philadelphia. With Atlantic since 1933, shortly after he received a B.S. in chemical engineering from the University of Pennsylvania, Mr. Walton has been in the refinery, research, and development departments and was senior process engineer in

the cracking division before entering on his new job, which was brought about by the construction of a new 100 ton/day ammonia plant.

NEW ATOMIC ENERGY PLANT EXECUTIVES

Key assignments in the Goodyear Atomic Corp., subsidiary of The Goodyear Tire & Rubber Co., which will operate the government's new atomic energy installation in southern Ohio, were given to Albert J. Gracia and James A. Merrill.

Mr. Gracia for two years prior to his new assignment was assistant manager of Goodyear research and development. A graduate of Massachusetts Institute of Technology, Mr. Gracia joined Goodyear in 1928 and in 1942 was named manager of the chemical engineering division. He was instrumental in developing the company's continuous polymerization process of synthetic-rubber reduction, which was adopted by the government during the war.





J. A. Merrill

A. J. Gracia

James A. Merrill, who will head the laboratory division of the new corporation, joined Goodyear on his graduation from Massachusetts Institute of Technology in 1930. He has specialized in latex research, particularly for war production. During the war Mr. Merrill developed a material for bullet-sealing fuel cells for fighter planes which won him a War Production Board Citation of Individual Merit, one of six such citations awarded to men in industry out of a field of 400,000 nominations.

Louis M. Sherman has been named associate director of product development in charge of industrial chemicals of the Ethyl Corp. During the war Mr. Sherman was adviser on chemical plants for the U.S.-Brazil Joint Military Commission, and he later joined American Cyanamid, where he remained for six years.

Raymond F. Moran has been appointed resident manager and S. M. Cimino general superintendent of Westvaco Chemical Division, Newark, Calif. Mr. Moran has been with Westvaco for 15 years, Mr. Cimino for 13.

Appointment of Parker S. Dunn as vice-president in charge of production



of American Potash & Chemical
Corp., Trona.
Calif., was announced recently.
Mr. Dunn joined
the corporation in
July, 1951 as assistant vice-president
after having been
with the Potash
Company of Amer-

ica for 10 years. He is a graduate of Ohio State University and has a master's degree from Massachusetts Institute of Technology.

Edward Mallinckrodt, Jr., chairman of the board of Mallinckrodt Chemical Works, St. Louis, Mo., received the 1952 Midwest Award of the A.C.S. St. Louis Section. His work in the purification of ether has greatly increased the effectiveness of the anesthesia and led to the development of a purification process for uranium that facilitated the atomic-bomb project.

S. M. Cavallaro has joined the staff of Fluor Corp., Ltd., Los Angeles, Calif., as process engineer. For the past five years he has been with U. S. Industrial Chemicals Co. and earlier was superintendent of operations for Petroleum Chemicals, Inc. He received a B.S. degree from the University of Rochester in 1938.

Edward A. Murray is opening a consulting service in the fields of textile

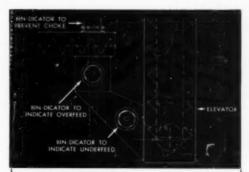
sizing and finishing in Anderson, S. C. He was in charge of the chemical section of the Deering Milliken Research Trust. Dr. Murray, who received a Ph.D. degree from the University of Texas, will also be affiliated with the



textile department of Clemson College for work on a special project in cotton finishing.

L. B. Parish, since June, 1952, has been director of the Marine Magnesium Products Division, Merck & Co., in south San Francisco, Calif. He had been transferred to that division in 1951 and prior to this transfer be held the position of assistant factory manager at the main plant of Merck & Co., Inc., Rahway, N. J.

Sidney M. Blair, formerly consulting chemical engineer of S. M. Blair Co., Toronto, Ont., Canada, is now vicepresident of Canadian Bechtel Ltd., and vice-president of Trans Mountain Oil Pipe Line Co.



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George O. G. Löf is now devoting himself to full-time consulting practice



in Denver, Colo., specializing in research planning, process design, and plant economics. Dr. Löf was formerly chairman of the department of chemical engineering and director of the Institute of Industrial Research at

the University of Denver. He received the Sc.D. degree from Massachusetts Institute of Technology in 1940,

Ernest O. Ohsol has joined Pittsburgh Coke & Chemical Co. as director of chemical engineering. He will be responsible for economic and engineering evaluations of major chemical products and will supervise development of process design and specifications.

Formerly with General Electric at Pittsfield, Mass., and with Esso Research Center of Standard Oil Development Co., Mr. Ohsol is a graduate of Massachusetts Institute of Technology.

Dr. Charles H. Prien has been named head of the chemistry division of the Institute of Industrial Research at the University of Denver. On the Institute staff since 1948, Dr. Prien will continue to serve also as its administrator of international projects. Dr. Prien was formerly a member of the chemical engineering faculty at the University of Colorado and has a Ph.D. degree from Purdue University.

Dr. Glenn H. McIntyre has been named the new technical director of

Ferro Corp., Cleveland, and will also continue his post as vice-president. Dr. McIntyre went to Ferro in 1927 after completing a fellowship at Western Reserve University sponsored by one of the founders of Ferro. He held the



positions of chief chemist and research director before becoming vice-president in 1947.

Raymond A. Mugele, chemical engineer with Shell Development Co., Emeryville, Calif., attended a summer session course at Massachusetts Institute of Technology on theory and operation of digital computers.

Donald Q. Kern, formerly director of engineering, Patterson Foundry & Machine Co., New York, N. Y., is now director of engineering, Manning & Lewis Engineering Co., Newark, N. J. Seymour Schwartz announced recently the formation of S. Schwartz &



Associates, consulting engineers of New York. The organization will specialize in the field of sulfur processing and recovery, providing technical designs, improvements, and economic evaluations.

Previously Mr. Schwartz was associated with Allied Chemical & Dye Corp., where he worked on sulfur problems, and with the Southern Acid & Sulphur Co.

Odon S. Knight has been named chief engineer of S. B. Penick Co., New York. Mr. Knight was formerly with Commercial Solvents Corp. as administrative assistant to the chief engineer.

Necrology

OTTO B. MAY

Otto B. May, president of Otto B. May, Inc., Newark, N. J., a textile dyestuffs manufacturing company, died Oct. 26. Born in Germany, he was educated abroad and came to the United States in 1907. From 1911-1918 he served as chemist and manager of Johann Hoff Co., manufacturer of malt extract and pharmaceuticals, Newark. Subsequently he organized the May Chemical Works, manufacturing chemicals and dves. In 1929 the Calco Chemical Co. bought the May Chemical Works. Dr. May served as a Calco executive until 1931, when he repurchased his factories and set up Otto B. May, Inc. Dr. May was 72 years old.

RITCHIE PATTERSON TAYLOR

Ritchie Patterson Taylor, chemical supervisor of Davison Chemical Corp., Curtis Bay Works, Md., died on September 8, 1952. With the Davison Co. for seven years after his graduation from the University of Maryland, Mr. Taylor was for several years research chemist with Tennessee Copper Co. before rejoining Davison.

ALBERT E. WEINHARDT

Albert E. Weinhardt, research chemical engineer with the Du Pont Co., died on Sept. 6. He was a graduate of Drexel Institute of Technology and had been employed for eight years in the office of scientific research and development of the University of Pennsylvania.

(More Necrology on page 66)

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Advertisements in the Classified Section of Chemical Engineering Progress are payable in advance, and are placed at 15c a word, with a minimum of four lines accepted. Box number counts as two words. Advertisements average about six words a line. Members of the American Institute of Chemical Engineers in good standing are allowed one six-line insertion (about 36 words) free of charge per year. More than one insertion to members will be made at half rates. In using the Classified Section of Chemical Engineering Progress it is agreed by prospective employers and employees that all communications will be acknowledged, and the service is made available on that condition. Boxed advertisements are available at \$15 per inch. Size of type may be specified by advertiser. In answering advertisements all box numbers should be addressed care of Chemical Engineering Progress. Classified Section, 120 East 41st Street, New York 17, N. Y. Telephone ORegon 9-1560. Advertisements for this section should be in the editorial offices the 15th of the month preceding the issue in which it is to appear.

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Knowledge of industrial chemical processes, raw materials and products desired. M.S. or Ph.D. preferred.

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NATURAL GAS ENGINEER — M.S.Ch.E. Registered professional engineer. Age 30. Six years' experience in natural gas processing plants and pipeline sales arrangements. Will accept suitable position in same or related field. Box' 7-12.

related need. Dot F1/2.

ASSOCIATE MEMBER—Ph.D. chemical engineer. 10. No conventional experience, but six varied years on atomic energy programs around country, in research, development, production, design supervision: now in operations research. Married, family, want to settle permanently. Seeking responsible position in research, development, administration, or management. Analytical mind, organizing ability; strong in initiative, financial accentific interests. Thesis on bubble mechanics. Box 8-12.

CHEMICAL ENGINEER — B.S.Ch.E. 1944.
Age 29, married with two children. Eight years' industrial experience with excellent references. Interested in design, construction, cost-estimating, instrumentation, etc. Desire to locate in Central, Southwest, or South Central U.-S. 37000. Box 9-12.

CHEMICAL ENGINEER — M.Ch.E. Eight years' experience in process development, trouble shooting, and design and start-up of chemical plants. Publications, patent. Desire position requiring initiative with growing consulting or chemical company. Prefer West Coast or metropolitan area. Box 10-12.

CHEMICAL ENGINEERING evening student, graduating June, 1953, Cooper Union Age 23. Excellent schighastic rescord, illuent French and German. Desire chemical engineering work in New Jersey or Manhattan. Box 11-12.

CHEMICAL PROCESS ENGINEER — M.S.E.
Ten years' development and plant experience. Desire responsible engineering position with a progressive company. Challenging work and opportunity for advancement essential. Midwest preferred. Résume on request. Box 12-12.

CHEMICAL ENGINEER—Age 34, family. Five years' experience in process design, operations and planning, in all phases of Fischer-Tropach program, 2½ years in Manhattan Project, five years other diversified experience. Box 13-12.

CHEMICAL ENGINEER — B.Ch.E. 1948. Family, veteran. Diversified experience with heavy chemicals firm including production supervision, process and design engineering and process development. Desire challenging position in any related field. Piref N. Y. area. Box 14-12.

CHEMICAL ENGINEER—M.S., M.I.T., 1950, 2½ years' experience in research, development and pilot plant operation. Desire work in petroleum or chemical industry with opportunity for advancement dependent upon ability. Age 27. Married. Box 15-12.

CHEMICAL ENGINEER — M.Ch.E. Nine years' industrial experience in development, economic evaluation and engineering administration. Desire responsible position leading to technical management. N. Y.-Boston area or California preferred. Box 16-12.

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Jet Propulsion Laboratory 4800 Oak Grove Drive Pasadena 3, California

SITUATIONS WANTED

(Continued)

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CHEMICAL ENGINEER—M.S. 1947. Three years' process design and three years' process design and three years' petrochemical research experience. Desire position in either process design or research. Tau Beta Pl. Member Al. Ch.E. and A.C.5. New York area preferred. Box 17-12

MARKETING-SALES position wanted. B.S. chemical engineering. Fourteen years' experience development, production and sales. Now employed responsible position management small equipment manufacturer. Present salary \$12000. Age 33, family. Located Eastern U. S. Box 18-12.

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PRODUCTION CHEMICAL ENGINEER— Equivalent M.S. Two years' applied research and production experience, responsible charge of plants. Veteran. 29. Dealtre pilot plant or production work. Southwestern location preferred. Box 21-12.

CHEMICAL ENGINEER — B.S.Ch.E., 1942, Experience includes process and mechanical design of ammonia synthesis, nitric cid and ammonium nitrate units. Complete project responsibility, expansion planning, estimates and reports. Best references. Bux 22:12.





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NECROLOGY

(Continued from page 63)

L. O. NEWTON

L. O. Newton, honorary secretary of The Institution of Chemical Engineers, London, died suddenly on October 2 at the age of 70. He was a vice-president of the Institution in 1938 and 1939 and had served as chairman of the nominating committee for twelve years before his death.

Mr. Newton was managing director of Sofnol, Ltd., a consulting chemical engineer, and a member of Gray's Inn.

FREEMAN IRBY GIBSON

Freeman Irby Gibson, vice-president of the Carolina Sand & Gravel Co., and owner of the Gibson Construction Co., Augusta, Ga., died last June at the age of sixty-nine. He had been employed as general superintendent of by-products of the Southern Cotton Oil Co. before entering his own business in 1922. Mr. Gibson had a B.S. and an M.S. in chemical engineering from the University of Arkansas.

ERNEST H. CHAPIN

Word has been received of the death early this year of Ernest H. Chapin, Manager of industrial sales of the Foster Wheeler Corp., New York. Mr. Chapin joined the Foster Wheeler Corp. in 1927 in the designing department and early turned to the development and sales divisions, where he was responsible for several important developments. Mr. Chapin received a B.S. in chemical engineering from the University of Pennsylvania.

CARL V. HERRMANN

Carl V. Herrmann, area superintendent at Du Pont Co., Wilmington, Del., died on Oct. 19. Mr. Herrmann had been with Du Pont as an assistant chemist, sulfuric acid technician, and superintendent since his graduation from the Case School of Applied Science in 1931. He received an M.A. in chemistry from Western Reserve University in 1934.

SELAH S. TOMKINS

Selah S. Tomkins, chief chemical engineer at Consolidated Edison Co., New York, died on Oct. 29. Mr. Tomkins was a licensed professional engineer and had a B.S. in chemical engineering from New York University. He joined the Consolidated Gas Co. in 1917 and was in charge of the chemical laboratory at his death.

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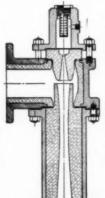
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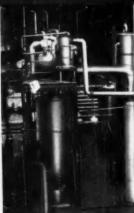
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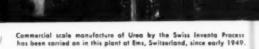
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